Electro Scientific Industries
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BRIDGES
AND
ACCESSORIES

SEPTEMBER 1963

MODEL

800

Instruction Manual

GENERATOR DETECTOR
DC

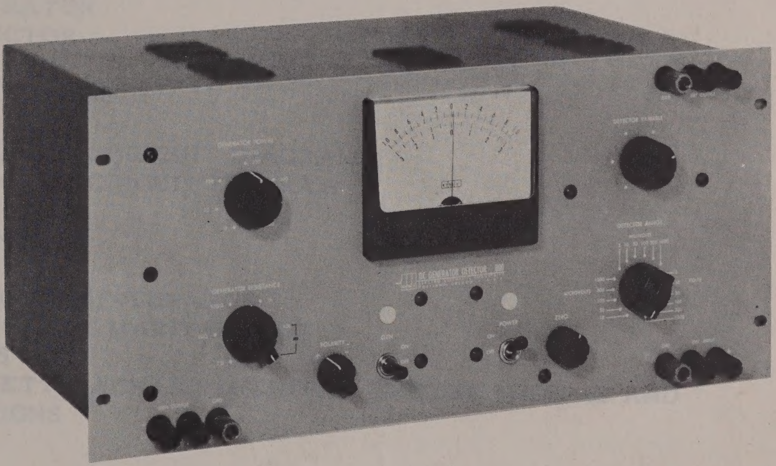

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TABLE OF CONTENTS

I. DESCRIPTION AND SPECIFICATIONS

- 1.1 DESCRIPTION
- 1.2 SPECIFICATIONS

II. OPERATING INSTRUCTIONS

- 2.1 TERMINALS AND CONTROLS
- 2.2 BASIC OPERATING PROCEDURE
- 2.3 USING THE 800 FOR BRIDGE MEASUREMENTS
- 2.4 USING THE 800 FOR VOLTAGE DIVIDER CALIBRATION
- 2.5 USING THE 800 FOR TOLERANCE CHECKING BY DEFLECTION
- 2.6 USING THE 800 AS AN ULTRA LOW RESISTANCE OHMMETER
- 2.7 USING THE 800 AS AN ULTRA HIGH RESISTANCE OHMMETER

III. THEORY OF OPERATION

- 3.1 GENERATOR
- 3.2 DETECTOR

IV. CIRCUIT DIAGRAMS

- 4.1 GENERATOR CIRCUIT DIAGRAM
- 4.2 DETECTOR CIRCUIT DIAGRAM

V. MAINTENANCE

- 5.1 ROUTINE MAINTENANCE
- 5.2 EMERGENCY MAINTENANCE
- 5.3 PARTS LIST
- 5.4 HEWLETT-PACKARD MICROVOLTMETER MANUAL AND REVISIONS

SECTION I

DESCRIPTION AND SPECIFICATIONS

1.1 DESCRIPTION

The 800 is a dc generator and null detector (microvoltmeter). The generator features double-chassis construction, or guarding, to greatly reduce stray leakage paths to ground. Leakage from the "high" generator terminal to ground has been completely eliminated. Insulation of the other terminal is kept to 10^{11} ohms or greater.

The output of the generator is continuously variable and is limited to a maximum of one watt into a matched load. A front panel control selects six output ranges to match loads from 1 ohm to 100 kilohms.

An automatic switching sequence allows the detector to remain connected to the bridge circuit except for approximately 2/3 seconds during switching transients. Correction can thus be made for thermal voltages by zeroing the detector while it is connected to the bridge circuit. At the same time, large transient voltages are prevented from causing a "zero" shift in the detector.

The detector features a very sensitive modulator-type dc amplifier. Trouble caused by stray ac pickup from the device under test is greatly reduced by a rejection filter. The modulator operates below the ac line frequency, thus still further reducing the ac pickup. The detector is designed to be operated with one terminal grounded.

The unique design features of the 800 make it suitable to a number of applications:

1. Very high resistance bridge measurements can be made with superior accuracy because of the special guarding and shielding features.
2. Very low resistance bridge measurements can also be made with high accuracy because of the detector sensitivity and the provision for matching the generator to the load.
3. The same features apply to make the 800 an ideal generator-detector combination for calibrating precision voltage dividers. A detailed description of this application may be found in ESI's "Design Ideas", volume 1, number 1. See also Section 2.4 of this Manual

4. The 800 can be used directly to measure extremely low conductance (high resistance). See Section 2.7.

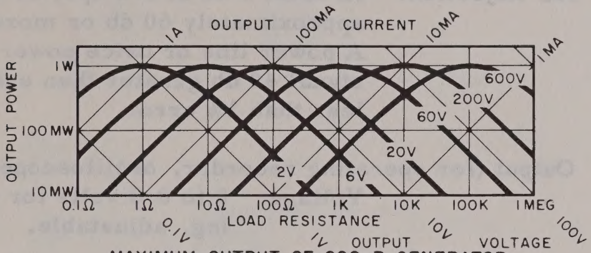
5. The 800 generator can be used separately wherever a variable, guarded, and power-limited dc supply is needed.

6. The 800 detector can be used separately as a microvoltmeter.

1.2 SPECIFICATIONS

1.2.1 GENERATOR

Range: 6 ranges, continuously variable, 0 to 600v. Power limited to 1 watt.



MAXIMUM OUTPUT OF 800-R GENERATOR

Insulation Resistance: Terminal 1 greater than 10^{14} ohms;
Terminal 2 greater than 10^{11} ohms.

Output Resistance:

OPEN CIRCUIT VOLTAGE (VOLTS)	2	6	20	60	200	600
SHORT CIRCUIT CURRENT (MA)	2,000	600	200	60	20	6
OUTPUT RESISTANCE (OHMS)	1	10	100	1K	10K	100K

1.2.2 DETECTOR

Voltage Range: Positive and negative and scale voltages of 10, 30, and 100 microvolts; 0.3, 1, 3, 10, and 30 millivolts; 0.1, 0.3, 1, 3, 10, 30, 300, and 1000 volts. 0.2 microvolts per division on the lowest range.

Accuracy: Within ± 5% of end scale. Power line frequency variations of ± 5 cps affect accuracy less than ± 2%.

Input Impedance: 1.2 megohms - operating
0.2 megohms - during switching

Amplifier Gain: 100,000 maximum

AC Rejection: At least 3 db at 0.2 cps; 50 db at 50 cps, and approximately 60 db or more above 60 cps. A power line or twice power line frequency signal 40 db greater than end scale causes less than 1% error.

Output (for operating recorder, oscilloscope, etc.):
Voltage: 0 to 0.8 volts for end scale reading, adjustable.

Output Impedance: 200 ohms shunted by a tapped 5000 ohm potentiometer.

Noise: Less than 0.2 microvolts rms (typically less than 1.2 microvolts p-p) referred to the input.

Drift: After 15 minutes warm up, drift is less than ± 2 microvolts per hour referred to the input.

1.2.3 PHYSICAL

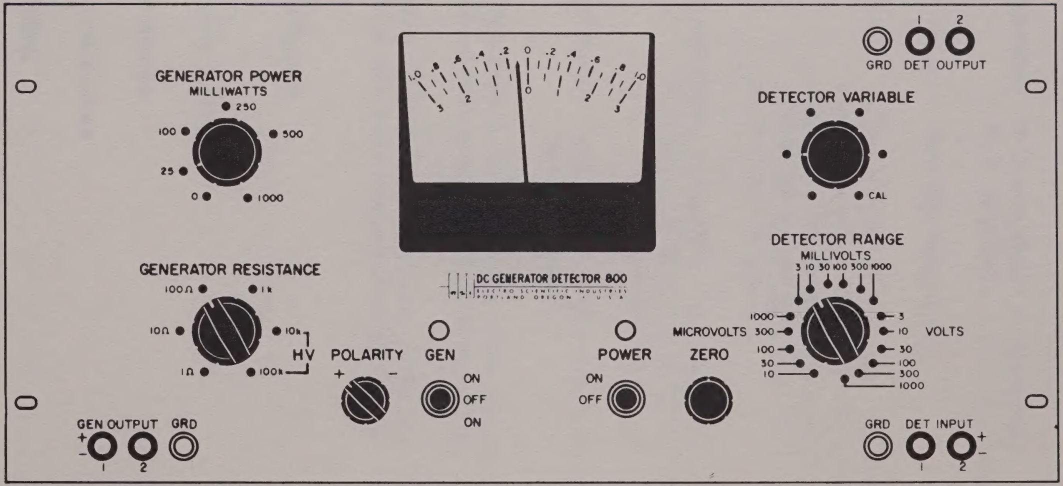
Height: 8-3/4 inches

Length: 19 inches

Depth: 11.43 inches

Weight: 25 lbs.

Power requirements: 115 v.a.c. ± 10%, 60 cps, 40 watts.



ESI MODEL 800 CONTROLS

SECTION II

OPERATING INSTRUCTIONS

2.1 TERMINALS AND CONTROLS

GEN OUTPUT Terminals: The lower left-hand terminals are for connecting the generator to an external circuit.

DET INPUT Terminals: The lower right-hand terminals are for connecting the detector to an external circuit.

DET OUTPUT Terminals: These terminals are provided so an external meter or recorder may be conveniently connected to the detector.

ZERO Control: The zero control adjusts the meter zero.

DETECTOR RANGE Selector: The bottom right-hand knob selects the maximum sensitivity of the detector.

DETECTOR VARIABLE Control: The top right-hand knob continuously varies the maximum sensitivity which is set with the DETECTOR RANGE SELECTOR.

GENERATOR POWER Control: The top left-hand knob varies the power output level of the generator from 0 to 1 watt maximum.

GENERATOR RESISTANCE Selector: The bottom left-hand knob selects the generator output voltage and a matching limiting resistor.

POLARITY Selector: This control determines the polarity of the generator.

GEN Switch: The up position of the GENERATOR switch turns the generator on. The down position is spring-loaded for momentary on operation.

POWER Switch: Controls line power to both generator and detector.

2.2 BASIC OPERATING PROCEDURE

This section describes the basic procedure for using the Model 800 to test or adjust any three-terminal or four-terminal resistive circuit by applying the generator output to one pair of terminals and observing the resulting signal at another pair of terminals with the detector. The procedure is applicable both to null balance applications, such as bridge balancing and voltage divider calibration, and the meter deflection applications, such as ohmmeter, attenuator and unbalanced bridge measurements.

Various specific applications are discussed in the sections of the manual following this one. The basic operating procedure for all of these applications is as follows:

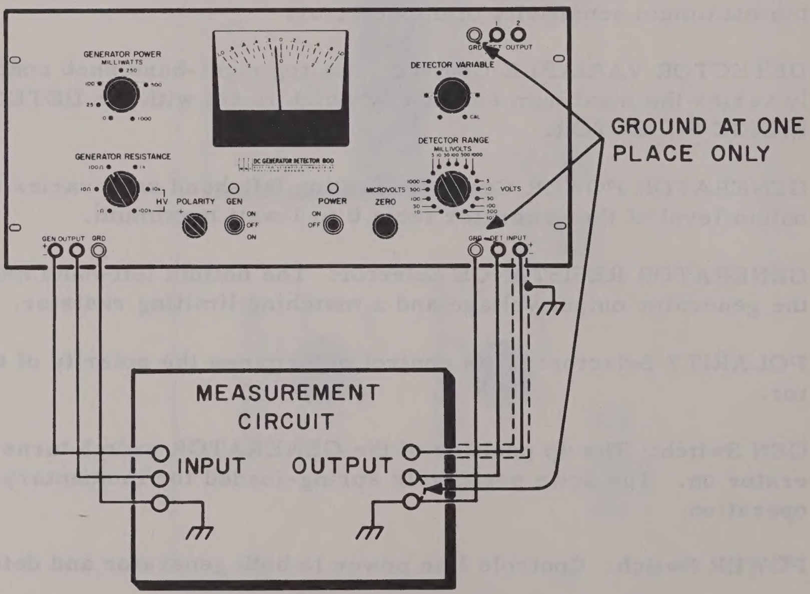


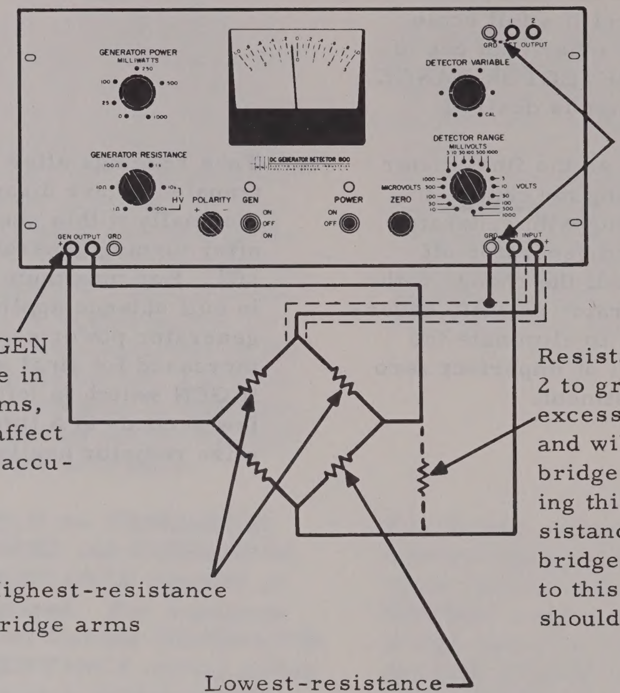
Fig. 2.2

1.	Be sure the GEN switch is off, then turn the POWER switch on and allow time for warmup.	The lowest detector ranges require about fifteen minutes warmup for minimum zero drift.
2.	Connect the circuit to be measured to the GEN OUTPUT and DET INPUT terminals as shown in Fig. 2.2. See that either DET INPUT 1 or DET OUTPUT 1 connection is grounded at one point only, so that ground loop currents between chassis cannot flow through these leads.	Be sure that there is no connection between output and ground at the terminals on the rear of the detector before making the above ground connection.
3.	Set the DETECTOR VARIABLE control at CAL.	This makes the meter most sensitive and adjusts full scale to the range setting.
4.	Set the DETECTOR RANGE switch at 30 microvolts and adjust the ZERO control for meter zero.	Always adjust zero with detector input connected to the measurement circuit - not open or short circuited - in order to cancel effects causing zero shift with change in source resistance.
5.	Change the DETECTOR RANGE switch to a range higher than the voltage expected when the generator is first turned on.	This will avoid "meter recovery" delays caused by input signals greater than full scale.
6.	Set the GENERATOR POWER control to a value which will not cause resistance changes due to heating.	A power setting lower than the lowest-rated resistor in the measurement circuit is always safe.
7.	Set the GENERATOR RESISTANCE control as desired.	At a setting approximately equal to the input resistance of the measurement circuit, the generator output will be a maximum, and will be approximately equal to the generator power setting.

8.	Set the generator POLARITY switch as desired; the marking indicates the polarity of the GEN OUTPUT 1 terminal.	The detector polarity is fixed, the direction of the meter deflection corresponding to the polarity of the DET INPUT 2 terminal.
9.	Turn the GEN switch on, pressing the handle either down for spring-return action or up for detented position. When the GEN switch turns the generator either on or off, an internal switch also shorts the detector input for approximately 1/2 second to protect it from reactive circuit transients; during the shorted period, a 200 kilohm resistor is internally connected across the DET INPUT terminals.	To increase the time the detector is shorted, press the GEN switch down for only 1/4 second, wait a suitable length of time, then press the GEN switch again (either down or up) to activate the detector. To observe circuit reactance transients without detector shorting, use the generator POLARITY reversal.
10.	Adjust the GENERATOR POWER and GENERATOR RESISTANCE controls as required. For maximum power find the GENERATOR RESISTANCE setting giving maximum detector deflection. To reduce the power below the GENERATOR POWER setting, use GENERATOR RESISTANCE settings away from the maximum setting - both voltage and current will be reduced as a result of resistance mismatch in either direction.	For further reduction of power, connect either a low-value shunt resistor across the GEN OUTPUT 1 and 2 terminals or a high-value series resistor in the GEN OUTPUT 1 lead, and use a GENERATOR RESISTANCE setting far away from the value of the shunt or series resistor.

11.	Change the DETECTOR RANGE setting as required for detector sensitivity. Use the DETECTOR VARIABLE control if a full scale value other than one of the DETECTOR RANGE settings is desired.	Turn off the GEN switch and recheck detector ZERO adjustment each time DETECTOR RANGE is changed toward higher sensitivity.
12.	Take as the final meter reading the change in reading with generator on and generator off (or half the change with generator polarity reversal), to eliminate the effect of imperfect zero adjustment.	Take readings after switching transients have disappeared (normally within one second after turning generator on or off). For maximum sensitivity in null balance applications, generator power can often be increased for final adjustment if GEN switch is left on only a few seconds at a time to minimize resistor heating.

2.3 USING THE 800 FOR BRIDGE MEASUREMENTS



GROUND AT ONE PLACE ONLY

Resistance from GEN 1 to ground will be in excess of 10^{14} ohms, which should not affect the measurement accuracy.

Resistance from GEN 2 to ground will be in excess of 10^{11} ohms and will shunt this bridge arm. By making this the lowest resistance arm of the bridge the error due to this resistance should be negligible.

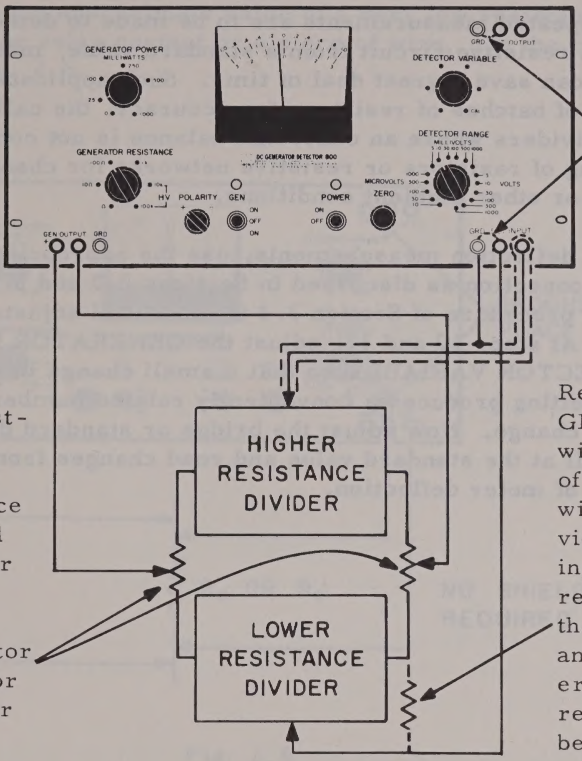
Highest-resistance bridge arms

Lowest-resistance bridge arm

Fig. 2.3

Connect the bridge to the GEN OUTPUT and DET INPUT terminals as shown in Fig. 2.3, then balance bridge following basic operating procedure of Section 2.2.

2.4 USING THE 800 FOR VOLTAGE DIVIDER CALIBRATION



Resistance from GEN 1 to ground will be in excess of 10^{14} ohms which should not affect the measurement accuracy.

GROUND AT ONE PLACE ONLY

Adjust end resistance so that detector shows no voltage difference at maximum and minimum divider settings (ESI Model LC-875 Lead Compensator recommended for precision divider calibration).

Resistance from GEN 2 to ground will be in excess of 10^{11} ohms and will shunt this divider. By making this the low resistance end of the lower resistance divider the error due to this resistance should be negligible.

Fig. 2.4

Connect the pair of dividers or attenuators to the GEN OUTPUT and DET INPUT terminals as shown in Fig. 2.5, then adjust to find pairs of settings giving detector null indications, following the basic operating procedure of Section 2.2.

2.5 USING THE 800 FOR TOLERANCE CHECKING BY DEFLECTION

Where repeated measurements are to be made to detect small variations of a resistive circuit from a standard value, meter deflection methods can save a great deal of time. Such applications are the checking of batches of resistors for accuracy, the calibration of voltage dividers where an exact null balance is not convenient, or the testing of resistors or resistive networks for changes with temperature or other ambient conditions.

For such deflection measurements, use the appropriate bridge or divider connection as discussed in Sections 2.3 and 2.4. Follow the basic procedure of Section 2.2 in the initial adjustment of the circuit. At steps 10 and 11, adjust the GENERATOR POWER or the DETECTOR VARIABLE so that a small change in the bridge or divider setting produces a conveniently related number of divisions of meter change. Now adjust the bridge or standard divider for a meter null at the standard value and read changes from this value in terms of meter deflection.

2.6 USING THE 800 AS AN ULTRA LOW RESISTANCE OHMMETER

To measure the approximate value of a very low resistance, such as a switch or relay contact or a piece of wire, use the circuit shown in Fig. 2.6.

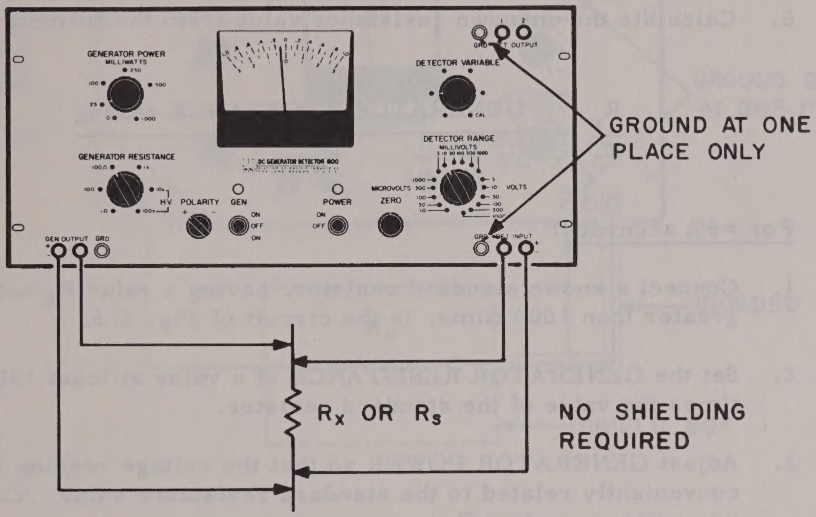


Fig. 2.6

Follow the basic procedure of Section 2.2 with the following additions:

For ± 20% accuracy:

1. Before connecting the unknown resistance, connect the DET INPUT leads directly to the GEN OUTPUT leads.

2. Set the GENERATOR RESISTANCE at a value at least 10 times the value of the unknown resistor.

3. Adjust GENERATOR POWER so that the voltage reading is an exact power of 10. Call this voltage reading E_G.

4. Connect the unknown resistor R_x in the circuit of Fig. 2.6.

5. Leaving GENERATOR RESISTANCE and GENERATOR POWER settings alone, but changing DETECTOR RANGE as required, measure the voltage. Call this voltage reading E_x.

6. Calculate the unknown resistance value from the formula:

$$\frac{R_x}{E_x} = \frac{\text{GENERATOR RESISTANCE setting}}{E_G}$$

For ±5% accuracy:

1. Connect a known standard resistor, having a value R_s not greater than 1000 ohms, in the circuit of Fig. 2.6.

2. Set the GENERATOR RESISTANCE at a value at least 100 times the value of the standard resistor.

3. Adjust GENERATOR POWER so that the voltage reading is conveniently related to the standard resistance value. Call this voltage reading E_s.

4. Remove the standard resistor and connect the unknown resistor R_x.

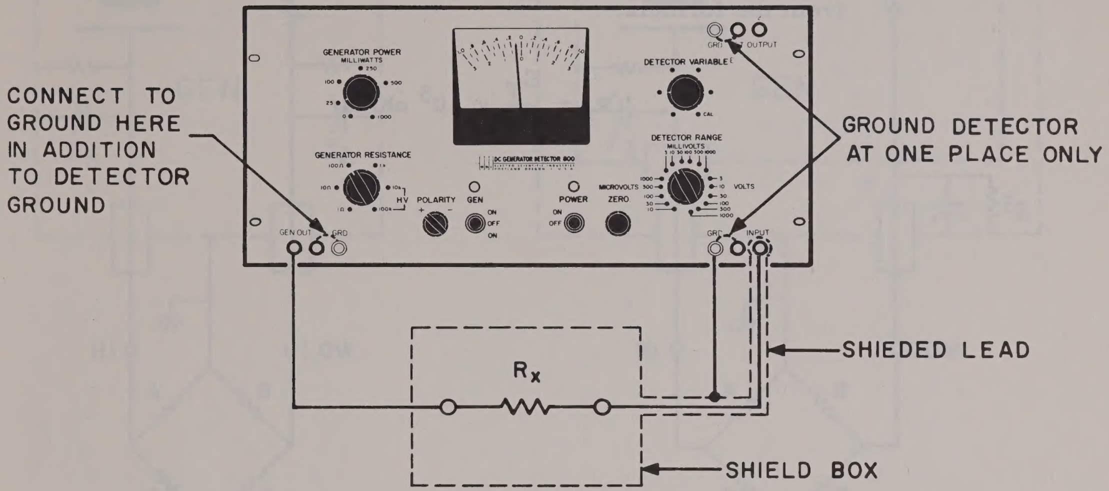
5. Leaving GENERATOR RESISTANCE and GENERATOR POWER settings alone, but changing DETECTOR RANGE as required, measure the voltage. Call this voltage reading E_x.

6. Calculate the unknown resistance value from the formula:

$$\frac{R_x}{E_x} = \frac{R_s}{E_s}$$

2.7 USING THE 800 AS AN ULTRA HIGH RESISTANCE OHMMETER

To measure the approximate value of a very high resistance, such as the leakage in an insulator, use the circuit shown in Fig. 2.7.


CONNECT TO GROUND HERE IN ADDITION TO DETECTOR GROUND

GROUND DETECTOR AT ONE PLACE ONLY

SHIEDED LEAD

SHIELD BOX

Fig. 2.7

Follow the basic procedure of Section 2.2 with the following additions:

1. Before connecting the unknown resistance, connect the DET INPUT 2 lead to the GEN OUTPUT 1 lead (or connect a short-circuit across the unknown resistance).

2. Set GENERATOR RESISTANCE at 100 kilohms.

3. Specify a test voltage E_T (500 volts typical) and adjust GENERATOR POWER so that the voltage reading is twelve-thirteenths of E_T (460 volts for E_T = 500 volts. (This corresponds to an open-circuit voltage E_T, since the 1.2 megohm detector input resistance will drop the voltage by one-thirteenth.)

4. Connect the unknown resistance R_x in the circuit of Fig. 2.7.

5. Leaving the GENERATOR RESISTANCE and GENERATOR POWER settings alone, but changing DETECTOR RANGE as required, measure the voltage. Call this voltage reading E_x.

6. Calculate the unknown resistance R_x or its conductance G_x from the formula:

$$R_x = \frac{E_T}{E_x} \times 10^5 \text{ ohms}$$

SECTION III

THEORY OF OPERATION

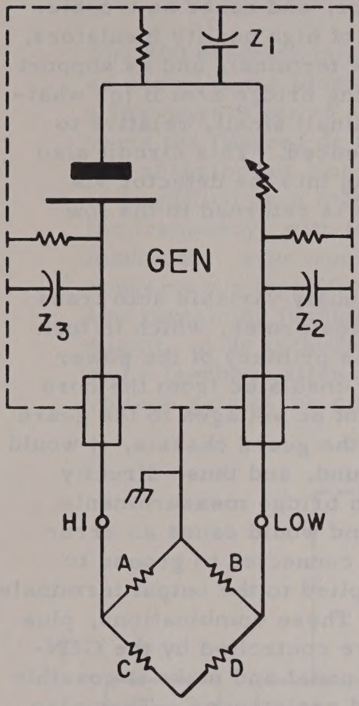


Fig. 3.1a

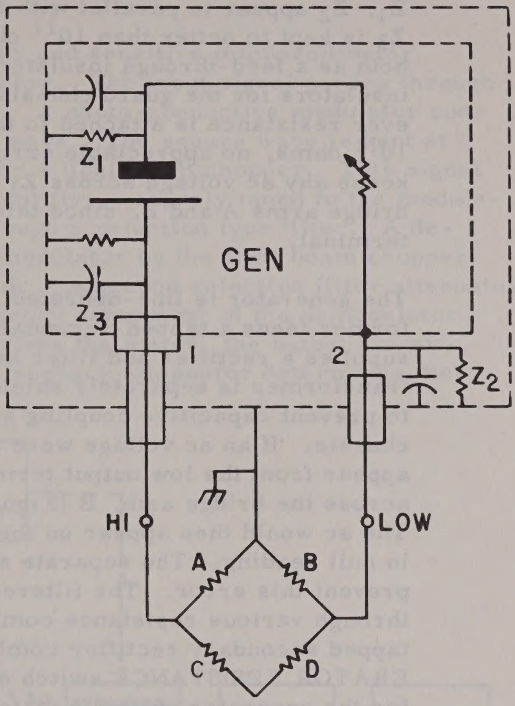


Fig. 3.1b

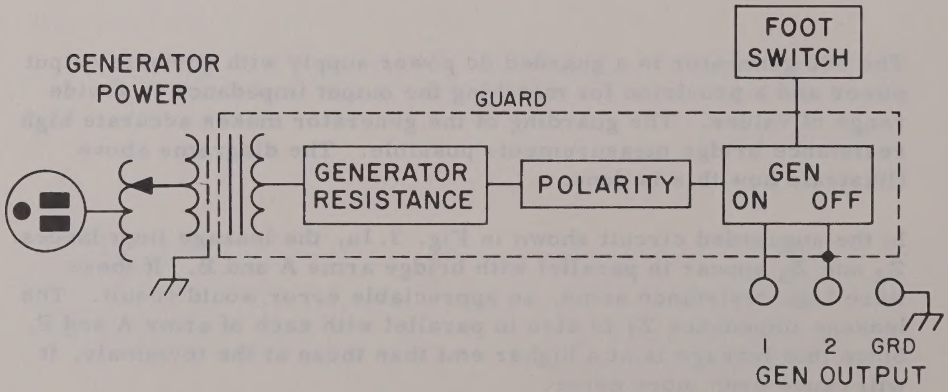
3.1 GENERATOR

The 800 generator is a guarded dc power supply with variable output power and a provision for matching the output impedance to a wide range of values. The guarding of the generator makes accurate high resistance bridge measurements possible. The diagrams above illustrate how this is done.

In the unguarded circuit shown in Fig. 3.1a, the leakage impedances Z_2 and Z_3 appear in parallel with bridge arms A and B. If these were high resistance arms, an appreciable error would result. The leakage impedance Z_1 is also in parallel with each of arms A and B. Since this leakage is at a higher emf than those at the terminals, it will cause even more error.

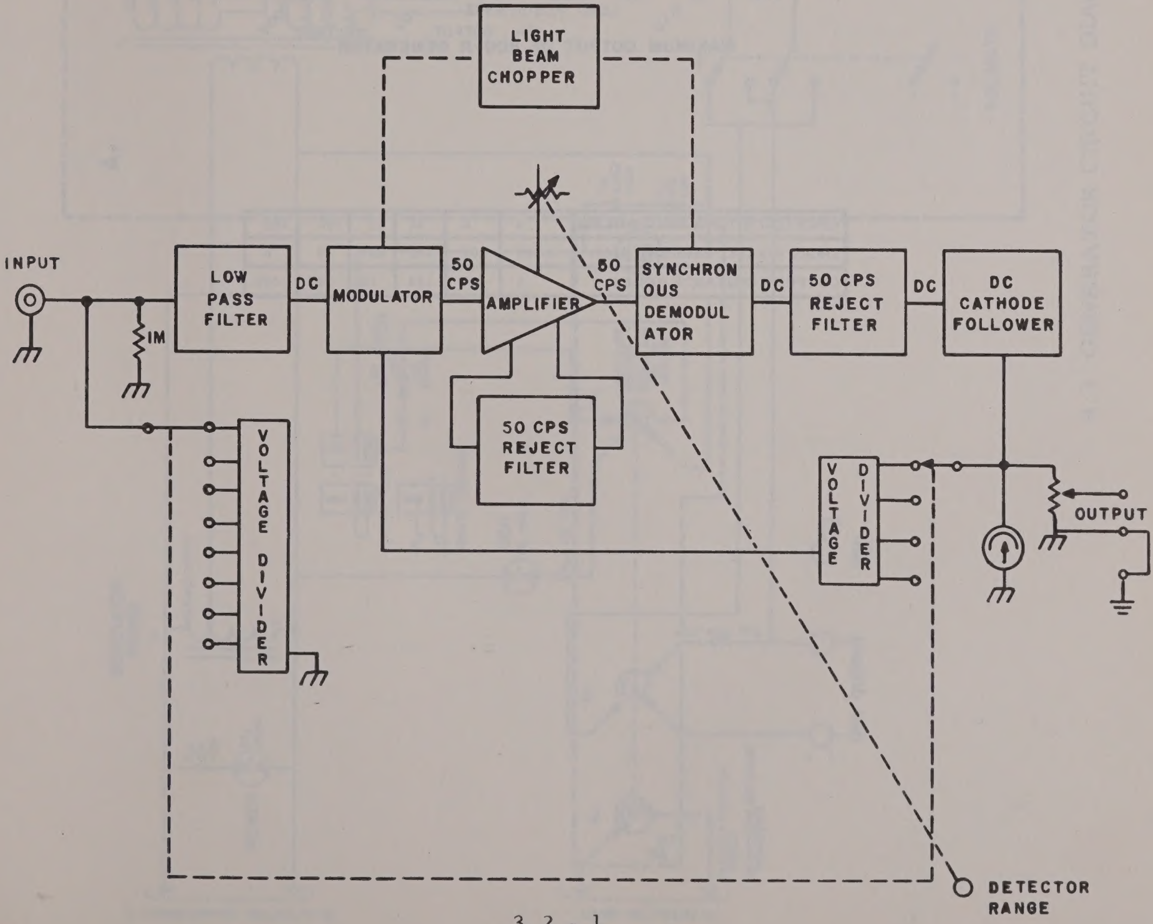
The 800 generator uses the guarded circuit as shown in Fig. 3.1b. Z_1, Z_2 appear in parallel with the generator, and cause no trouble. Z_3 is kept to better than 10^{11} ohms by use of high quality insulators, both as a feed-through insulator for the low terminal, and as support insulators for the guard chassis. By keeping bridge arm B (or whatever resistance is attached to the low terminal) small, relative to 10^{11} ohms, no appreciable error is experienced. This circuit also keeps any ac voltage across Z_1 from getting into the detector via bridge arms A and B, since this ac voltage is returned to the low terminal.

The generator is line-operated. A continuously variable auto transformer feeds a tapped-secondary power transformer, which in turn supplies a rectifier and filter network. The primary of the power transformer is separately shielded and air-insulated from the core to prevent capacitive coupling and leakage of ac voltages to the guard chassis. If an ac voltage were present on the guard chassis, it would appear from the low output terminal to ground, and thus, directly across the bridge arm, B (Figure above) in bridge measurements. The ac would then appear on the detector and would cause an error in null reading. The separate shielding is connected to ground to prevent this error. The filtered dc is supplied to the output terminals through various resistance combinations. These combinations, plus tapped secondary rectifier combinations are controlled by the GENERATOR RESISTANCE switch on the front panel and make it possible for the generator output to match most load resistances. They also limit the output power to one watt.

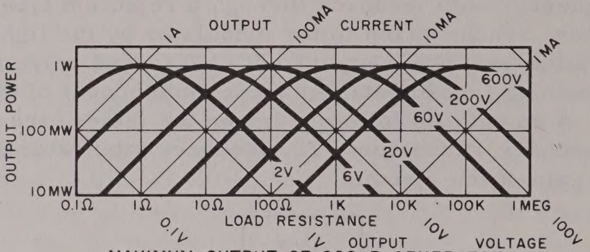


3.2 DETECTOR

The 800 detector is a dc amplifier and sensitive microvoltmeter, as shown in the block diagram below. The input signal passes through a low-pass filter to eliminate ac. A photo-conductive modulator converts the filtered dc to a square wave. The square wave is kept at 5/6 of the power line frequency by a light beam chopper. This signal is amplified by a high gain ac amplifier, sharply tuned to the modulator frequency, with feedback through a rejection type filter. A demodulator, synchronized to the modulator by the light beam chopper, converts the amplifier output to dc. A second rejection filter attenuates any remaining fundamental frequency component of the demodulator output. A dc cathode follower drives the meter, the output circuit, and a feedback attenuator. The feedback attenuator determines the voltage gain of the circuit.

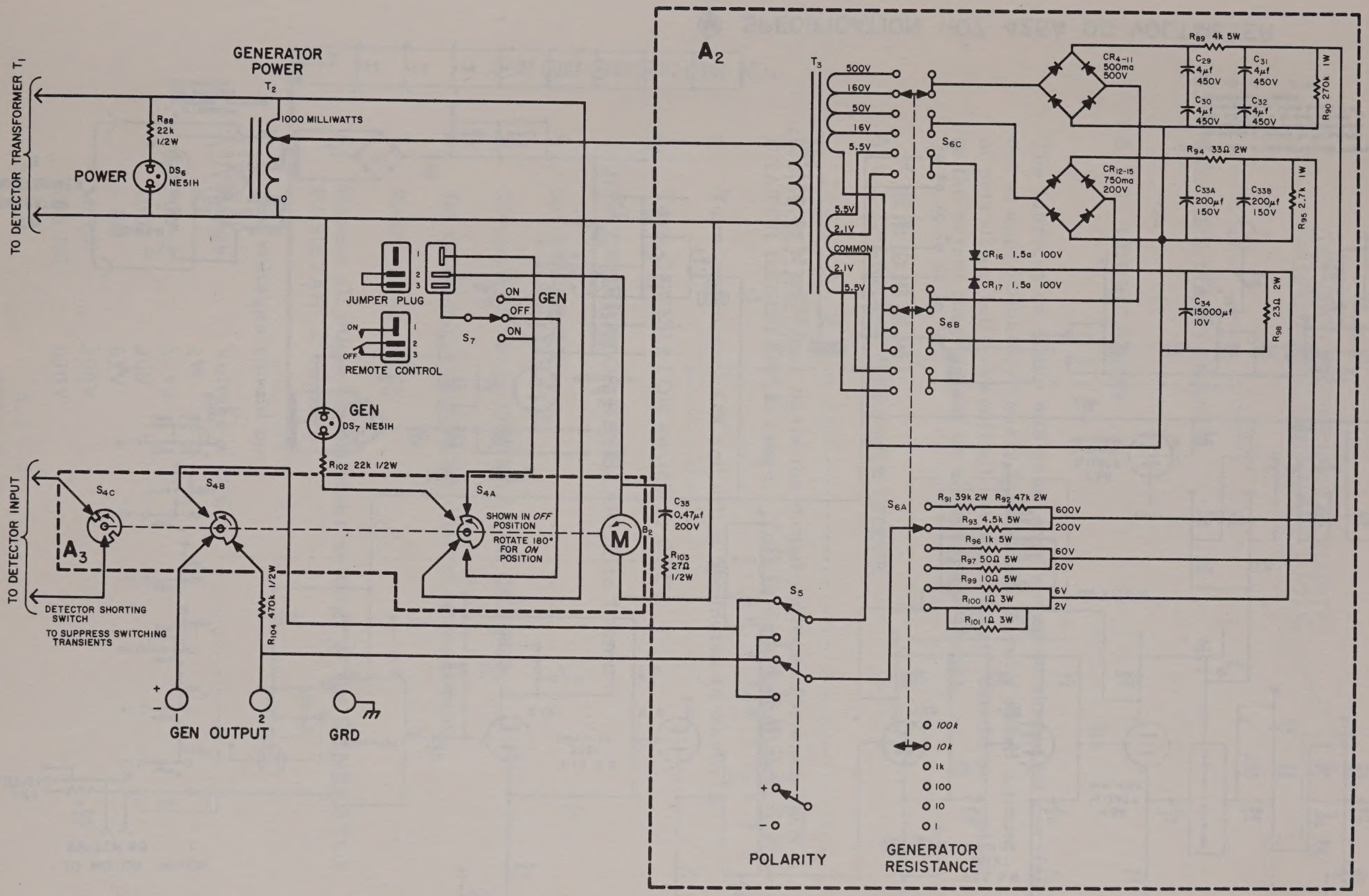


The generator power is supplied to the terminals through a motor-driven switching network. These controls momentarily disable the detector input during switching transients, and at the same time, connect a 470, 000 ohm resistor across the generator output terminals.

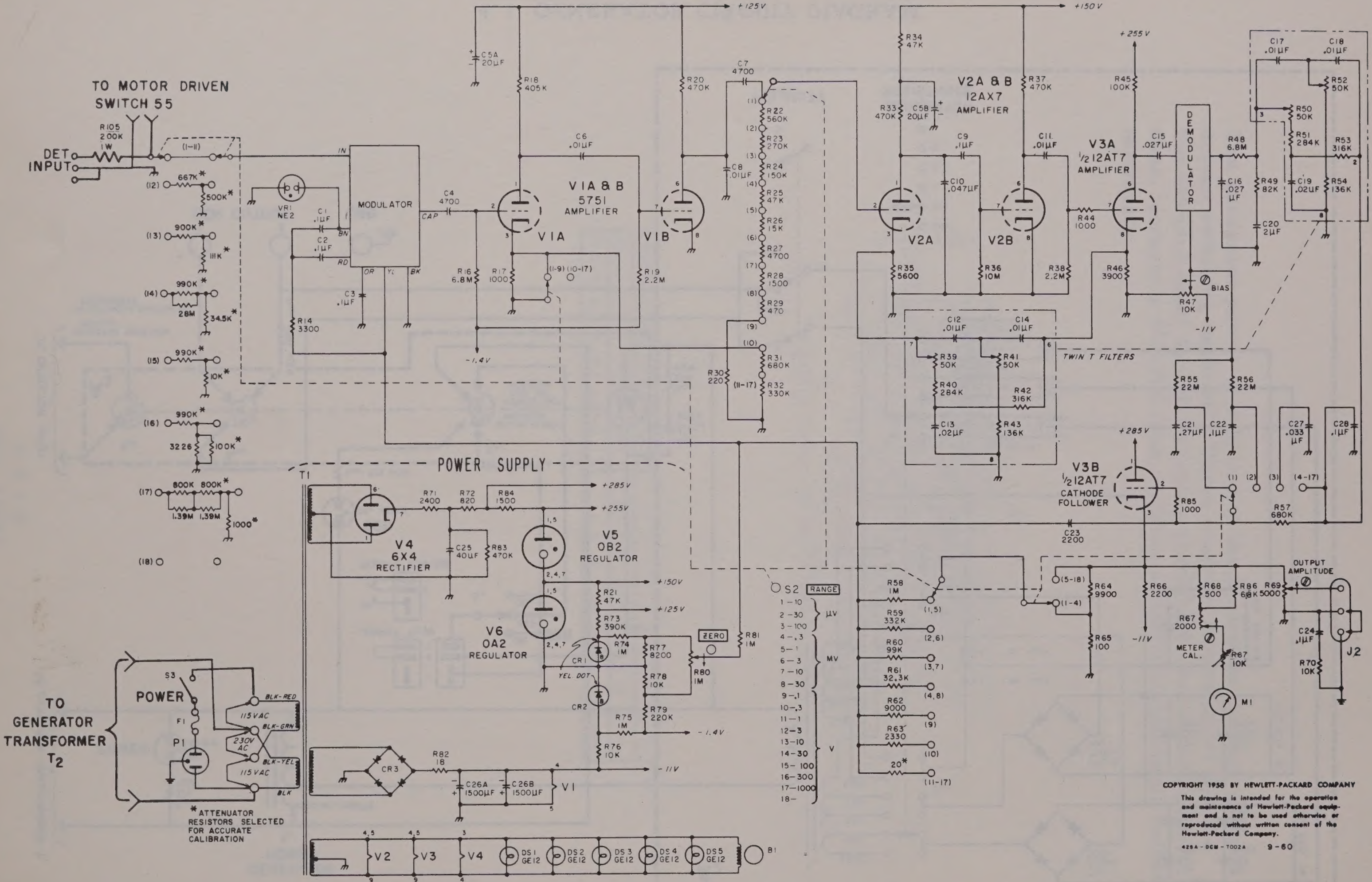


MAXIMUM OUTPUT OF 800-R GENERATOR

OPEN CIRCUIT VOLTAGE (VOLTS)	2	6	20	60	200	600
SHORT CIRCUIT CURRENT (MA)	2,000	600	200	60	20	6
OUTPUT RESISTANCE (OHMS)	1	10	100	1K	10K	100K



4.1 GENERATOR CIRCUIT DIAGRAM



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425A - DCM - T002A 9-60

SPECIFICATION H07 425A DC VOLTMETER

4.2 DETECTOR CIRCUIT DIAGRAM

SECTION V

MAINTENANCE

5.1 ROUTINE MAINTENANCE

5.1.1 LUBRICATION

The lubrication of the 800 generator switches should be carried out at approximately yearly intervals. A very small amount of petroleum jelly (Vaseline), or equivalent, should be applied to the detent mechanism on all rotary switches.

5.1.2 PERIODIC VOLTAGE CHECK

Check on a one-year basis the output voltages for each GENERATOR RESISTANCE range. This is done as follows:

1. Turn instrument ON and allow 5 minutes to warm up.
2. Turn GENERATOR switch to OFF.
3. Set GENERATOR RESISTANCE to 1 ohm.
4. Set POLARITY to +.
5. Connect VTVM to GENERATOR OUTPUT.
6. Set GENERATOR POWER control to maximum.
7. Read voltage.
8. Repeat all steps for all other settings of the GENERATOR RESISTANCE control.

The voltages should be:

Range	Voltage ± 20%
1Ω	2V
10Ω	6.3V
100Ω	20V
1 KΩ	63V
10 KΩ	200V
100 KΩ	630V

5.1.3 LEAKAGE RESISTANCE CHECK

To check the leakage resistance from each generator terminal to ground:

1. Connect jumper strap between detector input terminal #1 and ground.

2. Connect generator output terminal #1 to detector input terminal #2 with shielded lead and plug.

3. Cover terminal #2 of generator output with a grounded shield, make sure that the shield does not touch the terminal.

4. Adjust the generator output to 600 VDC.

5. Meter should read less than 6000 microvolts. (This is greater than 10^{11} ohms).

6. Connect generator output terminal #2 to detector input terminal #2 using shielded cable and plug. Again, as in test above, don't let plug touch terminal.

7. Set generator output to 600 VDC. With detector set on the 10 μV range, you should read not more than 6 μV on the meter.

5.2 EMERGENCY MAINTENANCE

CAUTION:

Unqualified personnel must not tamper with this instrument. If the tests outlined in the following paragraphs indicate the need for major repairs, our Service Department will be glad to furnish necessary repair information as well as any replacement parts. If the instrument is more than one year old, a reasonable charge may be expected for complete reconditioning if the instrument is returned to the factory. See the warranty at the back of this Manual.

5.2.1 GENERATOR

5.2.1.1 TROUBLE-SHOOTING CHART

SYMPTOM	POSSIBLE CAUSES	HOW TO FIND IT
1. Generator inoperative, pilot light not lit.	Before taking cover off: 1. Poor connection to line voltage. 2. Defective fuse. After taking cover off: 1. If, upon replacing fuse the new one blows also, the trouble may be a short in the (a) Wiring (b) Filter Capacitors, C29-34 (c) Rectifiers, CR4-17 (d) Transformer, T1	Isolate the short by turning down the Generator Power control to its full stop at zero. This effectively eliminates the generator from the circuit. If the short persists, see the HP Manual to trouble-shoot the detector. If the trouble is in the generator: (a) If it persists only on certain Generator Resistance ranges, the trouble is not in T1. This test also indicates which rectifier-filter network the short is in. (b) Disconnect at (A), (B), or (C) of the suspected network. If the short persists, it is probably due to a bad rectifier or shorted Generator Resistance switch. If the short is eliminated, it is probably due to a shorted filter capacitor, or the associated wiring.

SYMPTOM	POSSIBLE CAUSES	HOW TO FIND IT
2. No output on all ranges. Pilot light lit.	Before taking cover off: 1. Be sure controls have been set according to Section 2. After taking cover off: 1. Generator switch not making proper contact: (a) Bent contact (b) Inoperative Motor-B2 2. Polarity switch not making proper contact 3. Broken wire or bad solder joint. 4. Open primary on T1	
3. No output on one or more adjacent ranges.	Before taking cover off: 1. Be sure controls have been set according to Section 2. After taking cover off: 1. Generator Resistance switch not making proper contact. 2. Open resistor, R89, 91, 92, 93, 94, 97, 100, 101. 3. Broken wire or bad solder joint.	If the transformer T1, and the switches are found to be good, all the resistors of the inoperative range should be checked by disconnecting one end and testing with an ohmmeter.

SYMPTOM	POSSIBLE CAUSE	HOW TO FIND IT
4. Output too low on some ranges.	After taking cover off: 1. One or more rectifiers bad. 2. Shorted turns in secondary of T1.	Isolate the trouble by noting which ranges show difficulty. If trouble is on adjacent ranges using the same rectifier network, the trouble is probably a bad rectifier. A quick test for a bad rectifier is accomplished by using a high impedance voltmeter to check the voltages across each one. In each bridge, the voltage should be the same across each rectifier.

5.2.2 DETECTOR SECTION

The detector section of the Model 800 is a specially modified version of the Hewlett-Packard Model 425A Microvolt-Ammeter. An HP Instruction Manual is included with each instrument. The additions and corrections shown in the front of that Manual should be noted.

5.3 PARTS LIST ESI MODEL 800

The following parts list is in alpha numerical order of the circuit reference designator. Miscellaneous parts are included at the end of the list. Manufacturer of the part is given in a code number according to the Federal Supply Code for Manufacturers; see list of manufacturers below. Parts recommended as spares to sustain operation in isolated locations are indicated in the recommended spare parts column.

Parts manufactured by Electro Scientific Industries must be ordered from the factory. When ordering parts from the factory include the following information:

Model and serial number of the instrument
Electro Scientific Industries part number
Circuit reference designator
Description of part

CODE LIST OF MANUFACTURERS

00656	AEROVOX CORP. New Bedford, Mass.
01121	ALLEN-BRADLEY CO. Milwaukee, Wis.
11837	ELECTRO SCIENTIFIC INDUSTRIES, INC. Portland, Ore.
12697	CLAROSTAT MFG. CO., INC. Dover, N.H.
14655	CORNELL-DUBILIER ELECTRIC CORP. South Plainfield, N.J.
24455	GENERAL ELECTRIC, Lamp Division Cleveland, Ohio
37942	P R MALLORY AND CO. Indianapolis, Ind.
56289	SPRAGUE ELECTRIC CO. North Adams, Mass.

58474	THE SUPERIOR ELECTRIC CO. Bristol, Conn.
71785	CINCH MFG. CORP. Chicago, Ill.
76487	JAMES MILLEN MFG. CO., INC. Malden, Mass.
82389	SWITCHCRAFT, INC. Chicago, Ill.
84970	SARKES TARZIAN, INC. Bloomington, Ind.
94145	RAYTHEON MFG. CO. Newton, Mass.

Ckt Ref	Description	Mfr.	ESI Part No.	Qty Used	Recm SP
A_1	Assembly, Detector, (Modified Hewlett-Packard Model H 07-425A)	11837	8060	1	1
A_2	Assembly, Generator	11837	8008	1	1
A_3	Assembly, Motor, Sequence	11837	8090	1	1
B_2	Motor, Sequence, Part of Ass'y A_3	11837	8036	1	
C_1 - C_{28}	See Parts List in the Hewlett-Packard Manual				
C_{29} - C_{32}	Cap, Elect., 4μf, 450 wvdc, Mfr PN PRS 1530, Part of Ass'y A_2	00656		4	
$C_{33A, 33B}$	Cap, Elect., 200μf, 150 wvdc, Mfr PN PRS 1530, Part of Ass'y A_2	00656		1	

Ckt Ref	Description	Mfr.	ESI Part No.	Qty Used	Recm SP
C_{34}	Cap, Elect., 15000 uf, 10 wvdc, Mfr PN 10150, Part of Ass'y A_2	37942		1	
C_{35}	Cap, Mylar and Paper, 0.47 μf, 200 wvdc, Mfr PN 2TM-P47, Part of Ass'y A_2	56289		1	
$CR_{1, 2, 3}$	See Parts List in the Hewlett-Packard Manual				
$CR_4 - CR_{11}$	Diode, Silicone, 500 ma, 500 PIV, Mfr PN IN1764 Part of Ass'y A_2	94145		8	
$CR_{12}-CR_{15}$	Diode, Silicone, 750 ma, 200 PIV, Mfr PN F-2, Part of Ass'y A_2	84970		4	
$CR_{16, 17}$	Diode, Silicone, 1.5a, 100 PIV, Mfr PN 10J1, Part of Ass'y A_2	84970			
$DS_1 - DS_4$	See Parts List in the Hewlett-Packard Manual				
$DS_{5', 6}$	Lamp, Neon, Mfr PN NE51H	24455		2	
M_1	Meter	11837	8066	1	
$R_1 - R_{85}$	See Parts List in the Hewlett-Packard Manual				
R_{86}	Res, Fxd, Comp, 6.8K ± 10%, 1/2 w, Mfr PN EB6821	01121		1	
R_{87}	Res, Var, 10K, Mfr PN CU 1031	01121		1	

Ckt Ref	Description	Mfr.	ESI Part No.	Qty Used	Recm SP
R_{88}	Res, Fxd, Comp, 22K ±10%, 1/2 w, Mfr PN EB 2231, Part of Ass'y A_2	01121		2	
R_{89}	Res, Fxd, WW, 4K ±5%, 5w, Mfr PN VC5E, Part of Ass'y A_2	12697		1	
R_{90}	Res, Fxd, Comp, 270K ± 10%, 2w, Mfr PN HB2741, Part of Ass'y A_2	01121		1	
R_{91}	Res, Fxd, Comp, 39K ±10%, 2w, Mfr PN HB3931, Part of Ass'y A_2	01121		1	
R_{92}	Res, Fxd, Comp, 47K ±10%, 2w, Mfr PN HB4731, Part of Ass'y A_2	01121		1	
R_{93}	Res, Fxd, WW, 4.5K ±5%, 5w, Mfr PN VC5E, Part of Ass'y A_2	12697		1	
R_{94}	Res, Fxd, Comp, 33Ω ±10%, 2w, Mfr PN RC42, Part of Ass'y A_2	01121		2	
R_{95}	Res, Fxd, Comp, 2.7K ± 10%, 2w, Mfr PN HB 2721, Part of Ass'y A_2	01121		1	
R_{96}	Res, Fxd, WW, 1K ±5%, 5w, Mfr PN PR5F, Part of Ass'y A_2	12697		1	

Ckt Ref	Description	Mfr.	ESI Part No.	Qty Used	Recm SP
R_{97}	Res, Fxd, WW, 50Ω ±5%, 5w, Mfr PN PR5F, Part of Ass'y A_2	12697		1	
R_{98}	Same as R_{94}				
R_{99}	Res, Fxd, WW, 10Ω ±5%, 5w, Mfr PN PR5F, Part of Ass'y A_2	12697		1	
$R_{100, 101}$	Res, Fxd, WW, 1Ω ±5%, 3w, Mfr PN HVC3D, Part of Ass'y A_2	12697		1	
R_{102}	Same as R_{88}				
R_{103}	Res, Fxd, Comp, 27Ω ±10%, 1/2w, Mfr PN RC 20, Part of Ass'y A_2	01121		1	
R_{104}	Res, Fxd, Comp, 470K ±10%, 1/2w, Mfr PN EB4741, Part of Ass'y A_2	01121		1	
R_{105}	Res, Fxd, Comp, 200K ±5%, 2w, Mfr PN RC42	01121		1	
$S_{1, 2}$	See Parts List in the Hewlett-Packard Manual				
S_3	Switch, Lever, Power, Mfr PN 13004L	82389		1	
$S_{4a, 4b, 4c}$	Switch, Rotary, Det Input, Part of Ass'y A_3	11837	*	1	*

* Replace entire ass'y

Ckt Ref	Description	Mfr.	ESI Part No.	Qty Used	Recm SP
S_5	Switch, Rotary, Polarity, Part of Ass'y A_2	11837	*	1	*
$S_{6a, 6b, 6c}$	Switch, Rotary, Gen, Res, Part of Ass'y A_2	11837	*	1	*
S_7	Switch, Lever, Gen, Mfr PN 13036L	82389		1	
T_2	Transformer, Auto, Var, Mfr PN Powerstat 10B	58474		1	
T_3	Transformer, Power, Part of Ass'y A_2	11837	8091	1	
	MISCELLANEOUS				
	Coupler, Steatite, Mfr PN 39002	76487		3	1
	Binding Post	11837	1393	9	
	Cap, Binding Post, Ins	11837	1294	6	2
	Cap, Binding Post, Metal	11837	1296	3	1
	Insulator, Binding Post, Shoulder	11837	8823	6	
	Lens, Pilot Light	11837	8038	2	
	Knob, Round, Small	11837	1268	1	
	Knob, Bar, Large	11837	1266	2	
	Knob, Round, Large	11837	1271	2	
	Knob, Bar, Small	11837	1270	1	
	Socket, Footswitch, Mfr PN 261-12-03-010	71785		1	

* Replace entire ass'y

Ckt Ref	Description	Mfr.	ESI Part No.	Qty Used	Recm SP
	Plug, Footswitch, Mfr PN P-303 CCT	71785		1	1
	Shorting Strap	11837	3247	1	
	Clip, Footswitch Plug	11837	8108	1	

5.4 HEWLETT-PACKARD MICROVOLTMETER MANUAL AND REVISIONS

Number	Change
Specifications	As shown in the "Specifications" section of the 800 Manual
1 - 1	Delete, "and currents from 1 microampere to 3 miliamperes".
1 - 1	Change to read: "An input resistance of 1.2 megohm on all voltage ranges minimizes errors due to circuit loading".
1 - 1	Change, "It will deliver up to 1 milliampere at 1 volt", to "It will deliver up to 0.83 milliampere at 0.83 volt".
1 - 4	Delete 1 - 4 and add "The 800 can be converted to 230 operation on special order to the factory".
1 - 6	Delete
1 - 7	Delete
2 - 2	Delete. See Section 2 in the 800 Manual.
2 - 3	Delete
3 - 1	Delete the paragraph beginning "When operated as an ammeter, . . ."
4 - 3	a. Remove dust cover b. Connect jumper from junction of R_{48}, C_{16} to rotor of R_{47}. c. Set Range Switch on highest range (1000v). d. Turn instrument ON. Allow 15 minutes for warm-up. e. Observe meter. If it reads approximately ZERO (± 5% of end-scale), check is complete. f. If meter does not read near ZERO, adjust R_{47}, BIAS adjustment potentiometer, located on rear of instrument, to approximately zero meter. Meter response to this adjustment is sluggish and non-critical.
4 - 4	Delete

H.P. Manual Section Number	Change
4 - 5	Change "d" and "e" to: d. Set DETECTOR RANGE to 1000V position. e. Connect input of detector to a dc signal between 1 and 5 volts.
4 - 5	Omit "2".
4 - 9	Delete
4 - 10	Delete
Table 5-1	
DS_5	Delete
M_1	Delete
S_1	Delete

The rest of the Hewlett Packard Manual applies, with the exception of the circuit diagram. The diagram is a part of the 800 Manual.

CLAIM FOR DAMAGE IN SHIPMENT

This instrument should be tested upon receipt. If it fails to operate properly, or is damaged in any way, a claim should be filed with the carrier. A full report of the damage should be forwarded to us by the claim agent. We will then advise you of the disposition to be made and arrange for repair or replacement. Include model and serial number when referring to this instrument.

WARRANTY

Electro Scientific Industries, Inc. warrants each instrument and component parts to be free from defects in material and workmanship. Electro Scientific Industries, Inc. will service any instrument and replace parts thereof (except tubes, fuses and batteries) which shall, within one year after making delivery to the original purchaser, prove to be unsatisfactory.

If the fault has been caused by misuse or abnormal conditions or operation, a nominal charge will be made for repairs. In this case, an estimate will be submitted before making such repairs.

Electro Scientific Industries, Inc. reserves the right to make changes in design at any time without incurring obligation to modify units previously purchased.

Electro Scientific Industries
7524 S. W. Macadam Avenue • Portland 19, Oregon

ESI instruments are carefully engineered and made to the most exacting standards of workmanship and accuracy in a modern and well-equipped factory.

Field Engineers are maintained in principal cities as a service to our customers. Customers are invited to contact our nearest field engineer or to consult our engineering staff for further information regarding ESI instruments and their applications.

OPERATING AND SERVICING MANUAL

FOR

SPECIFICATION H07 425A

DC VOLTMETER

(Serials 002-02451 and above)

Specification H07-425A is similar to the standard Hewlett-Packard Model 425A Microvolt-Ammeter. It has been modified extensively for a specific application.

1. The instrument is supplied without cabinet, panel, meter, INPUT connector, probe assembly, or power switch.

2. All CURRENT ranges have been eliminated.

3. The following end scale voltage ranges are available: 10, 30, and 100 microvolts, 0.3, 1, 3, 10, and 30 millivolts, 0.1, 0.3, 1, 3, 10, 30, 100, 300, and 1000 volts. The attached schematic illustrates the special circuitry required to cover these ranges.

In all other respects the information in the standard Operating and Servicing Manual applies to these special instruments.

-----NOTE-----

> There may be minor discrepancies between your instrument and the attached special schematic. Always check the attached standard manual for the latest values on all components that have circuit references assigned.

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hp MANUAL CHANGES

MODEL 425A

MICROVOLT-AMMETER

Manual Serial Prefixed: 116-
Manual Printed: 6/61

To adapt this manual to instruments with other serial prefixes check for errata below, and make changes shown in tables.

Instrument Serial Prefix	Make Manual Changes
142-	1

Instrument Serial Prefix	Make Manual Changes

Errata

Table of SPECIFICATIONS,
Under AMPLIFIER, AC Rejection,
Change: 0.2 cps to 1 cps.....

Table of Replaceable Parts, under MISCELLANEOUS,
Change Input Amplifier Assembly hp Stock No. to 425A-58B.
Add Modulator Assembly; hp Stock No. 425A-23C.
Fuseholder: Change hp Stock No. to 1400-0084.

Figure 4-6,
V1, pin 2: Change 1.4V to -1.4V.

Figure 4-7,
Change the connection of V1A cathode as shown in Figure 1 below.

Change the value of C20 from 3 µf to 2 µf.

Table of Replaceable Parts,
C7: Change to read: "Capacitor, fixed, mylar, 4700 pf ±10%, 400 vdcw; hp Stock No. 0170-0021".

CHANGE 1

C4: Change to capacitor, fixed, 0.005 µf, 500 vdcw; hp Stock No. 0150-0014 as shown in Figure 1 below.

Add C31: Capacitor, fixed, ceramic, 100 pf ±10%, 500 vdcw; hp Stock No. 0150-0073 as shown in Figure 1 below.

Add R86: Resistor, fixed, deposited carbon, 10K ohms ±1%, 1/2W; hp Stock No. 0727-0158 as shown in Figure 1 below.

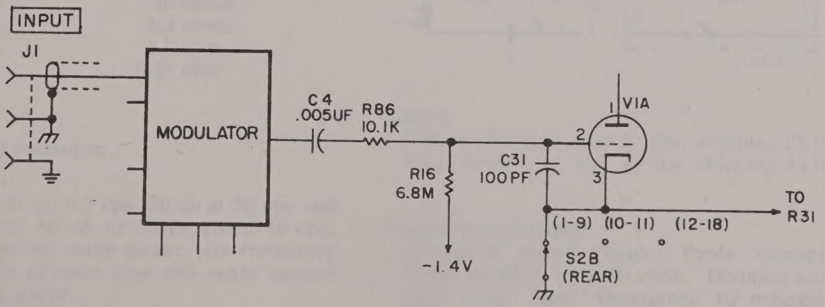


Figure 1.

4/11/62 - R
4/9/62

ESI 9/62

SPECIFICATIONS

VOLTMETER

Voltage Range:
Positive and negative voltages from 10 microvolt end scale to 1 volt end scale in an eleven step, 1, 3, 10 sequence.

Accuracy:
Within ±3% of end scale. Power line frequency variations of ±5 cps affect accuracy less than 2%.

Input Impedance: 1 megohm ±3%.

MICROAMMETER

Current Range:
Positive and negative currents from 10 picoamperes (pa) end scale to 3 milliamperes end scale in an eighteen step, 1, 3, 10 sequence.

Accuracy:
Within ±3% of end scale. Power line frequency variations of ±5 cps affect accuracy less than ±2%.

Input Impedance:
Depends on range, 1 megohm to 0.33 ohm.

Range	Impedance
10 pa (μμa)	1.000 megohm
30 pa	1.000 megohm
100 pa	1.000 megohm
.3 na (m μa)	1.000 megohm
1 na	1.000 megohm
3 na	0.333 megohm
10 na	0.100 megohm
30 na	0.033 megohm
.1 μa	0.010 megohm
.3 μa	3300 ohms
1 μa	1000 ohms
.003 ma	333 ohms
.01 ma	100 ohms
.03 ma	33 ohms
.1 ma	10 ohms
.3 ma	3.3 ohms
1 ma	1.0 ohm
3 ma	0.33 ohm

AMPLIFIER

Gain: 100,000 maximum.

AC Rejection:
At least 3 db at 0.2 cps, 50 db at 50 cps and approximately 60 db or more above 60 cps. A power line or twice power line frequency signal 40 db greater than end scale causes less than 1% error.

AMPLIFIER Cont'd

Output:
0 to 1 volt for end scale reading, adjustable (5000 ohm shunt potentiometer) 1 ma maximum at 1 volt output.

Output Impedance:
Depends on setting of output potentiometer; 10 ohms when potentiometer is set for maximum output.

Noise:
Less than 0.2 μv rms (typically less than 1.2 μv peak-to-peak) referred to the input.

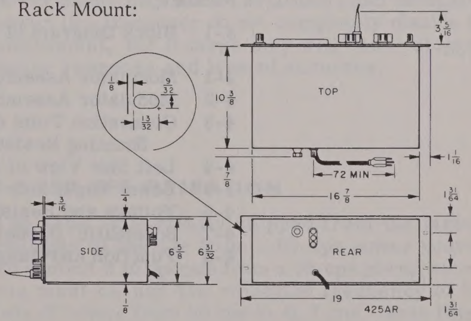
Drift:
After 15 minutes warm-up, drift is less than ±4 μv per day referred to the input.

GENERAL

Power:
115/230 volts ±10%, 60 cps, 40 watts.
50 cycle operation also available.

Dimensions:
Cabinet Mount: 7-3/8 inches wide, 11-3/4 inches high, 12 inches deep.

Rack Mount:



Weight:
Cabinet Mount: Net 17 lbs, shipping 23 lbs.
Rack Mount: Net 21 lbs, shipping 33 lbs.

Accessory Available:
425A-21B 1000:1 Divider Probe increases range of 425A to 1000 volts. Division accuracy ±2%, input resistance 10 megohms.

TABLE OF CONTENTS

Section — Page

I GENERAL DESCRIPTION I-1
- 1-1 General I-1
- 1-2 Applications I-1
- 1-3 Noise I-1
- 1-4 230-Volt Operation I-1
- 1-5 Power Source Frequency Stability I-1
- 1-6 50-cps Operation I-1
- 1-7 Damage in Transit I-1

II OPERATING INSTRUCTIONS II-1
- 2-1 Preliminary Considerations . . . II-1
- 2-2 Operating Instructions II-1
- 2-3 Isolating the Chassis II-2
- 2-4 Operation with a Recorder . . . II-2

III CIRCUIT DESCRIPTION. III-1
- 3-1 General III-1

IV MAINTENANCE IV-1
- 4-1 General IV-1
- 4-2 Mechanical Adjustment of Meter Zero IV-1
- 4-3 Periodic Check of Cathode Follower Bias Adjustment . . IV-1
- 4-4 Cabinet Removal IV-1
- 4-5 Check of Modulator Assembly . IV-1
- 4-6 Replacement of Modulator Assembly IV-2
- 4-7 Check of Demodulator Assembly IV-3
- 4-8 Adjustment of Twin-T Filters . IV-3
- 4-9 Disconnecting Input-Shunting Resistor IV-3
- 4-10 Replacement of Input-Shunting Resistor IV-4
- 4-11 Meter Calibration IV-4

V REPLACEABLE PARTS V-1
- 5-1 Introduction V-1
- 5-2 Ordering Information V-1

LIST OF ILLUSTRATIONS

Number — Title — Page

- 3-1 Block Diagram of 425A III-1
- 4-1 Modulator Assembly Output IV-2
- 4-2 Modulator Assembly IV-2
- 4-3 Connection Point of Input-Shunting Resistor IV-4
- 4-4 Left Side View of Model 425A IV-5
- 4-5 Lower Right Side View of 425A . . . IV-6
- 4-6 Voltage and Resistance Diagram . . IV-8
- 4-7 Schematic (Model 425) IV-9
- 4-8 Function and Range Switch Detail . . IV-10

LIST OF TABLES

Number — Title — Page

- 4-1 Trouble-Shooting IV-0
- 5-1 Replaceable Parts V-1

SECTION I
GENERAL DESCRIPTION

1-1 GENERAL

The Model 425A DC Microvolt-Ammeter is an extremely sensitive measuring device which measures voltages from 1 microvolt to 1 volt and currents from 1 picoampere to 3 milliamperes. An input resistance of 1 megohm on all voltage ranges minimizes errors due to circuit loading.

The 425A can make measurements in circuits which are off ground potential, for the chassis and input circuit may be isolated from the cabinet.

The 425A provides an output which will drive either potentiometer or galvanometer recorders. It will deliver up to 1 milliampere at 1 volt.

1-2 APPLICATIONS

The 425A has many applications. For example, in engineering: it is an excellent null detector or dc amplifier, and it will measure vacuum tube grid currents and leakage currents in insulators and capacitors; in medicine and biology: it will measure nerve potentials and plant cell potentials; and in physics and chemistry: the 425A is useful in ionization chamber measurements and can monitor thermocouple and galvanic actions.

1-3 NOISE

Noise in the 425A, is less than 0.2 microvolts rms referred to the input. Due to the random nature of noise, its magnitude is best expressed in terms of its rms value. Peak-to-peak value of the type of noise in the 425A is approximately six times the corresponding rms value. Peak-to-peak noise in a typical 425A, as indicated by the meter, is approximately 1 microvolt referred to the input.

1-4 230-VOLT OPERATION

The 425A is normally wired for use from a 115-volt, 60 cps power supply, but it can easily be converted for use from a 230-volt, 60 cps source by changing the dual 115-volt primary windings of the power transformer from a parallel combination to a series combination. At the time of the change, replace the 1 ampere, slow-blow line fuse with a .5 ampere, slow-blow fuse. See the schematic diagram for details.

1-5 POWER SOURCE FREQUENCY STABILITY

The 425A uses an ac-coupled amplifier which is tuned to a frequency 5/6 designated power line frequency. A synchronous motor determines frequency of the signal applied to the amplifier. Thus the instrument must be operated from a power source which does not vary in frequency more than ±5 cps. Most commercial power systems maintain frequency well within these limits; however, small portable power plants may not. Variations from designated power line frequency do not completely disable the instrument, but if large they will cause sluggish meter response and loss of accuracy.

1-6 50-CPS OPERATION

The 425A is normally shipped from the factory equipped to operate from a 60-cps power source. To convert it to operate from a 50-cps power source, you must change the rejection frequency of two twin-T filters from 50 cps to 41.7 cps. Both filters are contained in a single plug-in unit. Units designed to operate at 41.7 cps are available from the factory under stock number 9110-0039.

1-7 DAMAGE IN TRANSIT

Thoroughly inspect this instrument upon receipt. If there is any damage, see "Claim for Damage in Shipment" paragraph at the rear of this manual.

SECTION II
OPERATING INSTRUCTIONS

2-1 PRELIMINARY CONSIDERATIONS

a. Low Level Electrical Phenomena

You must consider stray voltages which are due to low-level electrical phenomena when measuring signals in the microvolt region. Thermocouples (thermoelectric effect), the flexing of coaxial cables (triboelectric effect), apparent residual charges on capacitors even after they have been shorted for some time (dielectric absorption), the battery action of two terminals mounted on an insulator (galvanic action) can all produce stray voltages.

Errors due to thermal voltages alone can be appreciable. The probe of the 425A is designed to have a very low thermoelectric effect with copper, the most common electrical conductor. In application, other materials may be encountered. Some likely materials (with their approximate temperature-emf characteristics versus copper) are constantan (40 μv/°C), steel (8 μv/°C), manganin (3 μv/°C), aluminum (3 μv/°C), and brass (2 μv/°C). As an example, some high-grade wire-wound resistors are wound with constantan wire (known under the trade names of "Eureka", "Advance", and "Ideal"). If the 425A is connected across such a resistor and there is 1.0°C temperature difference between the ends of the resistor, 40 microvolts will be developed.

Stray low-level electrical phenomena are present, in one form or another, in nearly all circuits. To hold them within tolerable limits, carefully select components and control temperature gradients.

Some suggested sources of more detailed information are given below:

Thermocouples:	Handbook of Chemistry and Physics, 39th Edition, Chemical Rubber Publishing Company, Cleveland, 1957.
Low-noise cables:	Data readily available from cable manufacturers.
Dielectric Absorption:	Brotherton, M.: "Capacitors, Their Use in Electronic Circuits", D. Van Nostrand Company, Inc., 1946, Chapters 1 and 8.

b. Ground Currents

Ground currents may cause an offset of meter zero on lower ranges of the 425A. These currents occur when the potential of the 425A cabinet differs from ground potential of the circuit under test. They flow through the probe cable and ground lead of the power cable, producing a voltage drop which is added to the input signal. To break the ground loop and eliminate the ground currents, remove the metal shorting strap between chassis-ground and cabinet-ground terminals of OUTPUT connector on rear of the instrument. This procedure isolates chassis from cabinet.

c. AC Voltages

The low-pass filter in the input circuit of the 425A provides more than adequate rejection of ac and transients normally encountered when measuring dc signals within range of the instrument. Choice of a modulator frequency different from line frequency prevents stray line-frequency pick-up from producing any error unless the ac amplifier is actually overdriven. Nevertheless, avoid excessive ac.

AC voltages can exist between chassis and cabinet without affecting accuracy of the instrument. For example, line frequency potential difference between chassis and cabinet can be 80 to 100 db greater than the full-scale dc value of the range selected. Maximum voltages between chassis and cabinet must not exceed 500 volts peak.

2-2 OPERATING INSTRUCTIONS

a. Attach probe to INPUT connector.

b. Turn instrument ON. It is ready for use within a minute. For maximum stability on lower ranges, allow approximately 15 minutes warm-up.

c. Set FUNCTION switch to desired function.

d. Set RANGE switch to desired range.

e. Clip probe and common clip together and adjust meter to zero with ZERO control. ZERO control has maximum range of about ±50 μv; thus it has diminishing effect on higher ranges.

NOTE

Do not handle the probe for three or four minutes prior to making zero adjustment on two most sensitive voltage and current ranges. Static charges and temperature gradients within the probe must have time to dissipate.

----

f. Connect probe to circuit. On more sensitive ranges, allow sufficient time for probe, common clip, and circuit connection points to reach thermal equilibrium before considering reading final.

NOTE

Do not overload the instrument excessively on higher current ranges, for current-shunting resistors are not protected from extreme overload.

If 1 megohm input-shunting resistor is disconnected in your instrument, calibration of the nine lowest current ranges is altered. To use these ranges, either shunt instrument externally with a 1 megohm resistor or reconnect input-shunting resistor (see paragraph 4-10).

2-3 ISOLATING THE CHASSIS

To isolate chassis of the 425A, remove the metal shorting strap between chassis-ground and cabinet-ground terminals of OUTPUT connector located on rear of instrument. Potential difference between chassis and cabinet must not exceed 500 volts peak. Isolate chassis under following conditions:

a. Measurement is between two points which are both above ground potential.

b. Measurement is with respect to a ground which is itself isolated.

c. Measurement is made on a more sensitive range (precaution against ground currents).

2-4 OPERATION WITH A RECORDER

a. If conditions require isolation of 425A chassis, isolate recorder chassis.

b. Connect recorder to OUTPUT connector of 425A.

c. Clip probe and common clip together and select 1 VOLT range.

d. Set recorder zero to desired position on its scale.

e. Select 30 MICROVOLT range on 425A, and adjust ZERO control to produce end-scale deflection on meter (30 microvolts).

f. Calibrate system by adjusting output AMPLITUDE control to produce desired deflection on recorder.

g. Set meter of 425A to zero with ZERO control. The system is now ready to record your measurements. Remember that deflection of recorder is proportional to meter deflection of 425A regardless of range selected.

SECTION III
CIRCUIT DESCRIPTION

3-1 GENERAL

If the 425A is considered a black box with two input terminals and two output terminals, it is a dc amplifier. Block diagram of Figure 3-1 indicates what is between input and output terminals. The input signal is applied across the input resistance, and any ac superimposed on the signal is attenuated by the low-pass filter. A photoconductive modulator converts the filtered dc to a square wave whose frequency is set at 5/6 power-line frequency by a light-beam chopper. The output of the modulator is amplified by a high-gain, ac-coupled amplifier tuned to modulator frequency by feedback through a rejection-type filter. A synchronous demodulator, synchronized with the modulator by the light-beam chopper, converts amplifier output to dc. A second-rejection-type filter attenuates any remaining fundamental frequency component of the demodulator output. A dc cathode follower drives a meter, output circuit, and feedback attenuator which determines voltage gain of the instrument.

When operated as an ammeter, the 425A actually measures voltage drop across a calibrating input resistance. However, this resistance varies on all but five lowest ranges to keep full scale voltage drop across the input of the instrument to a maximum of 1 millivolt.

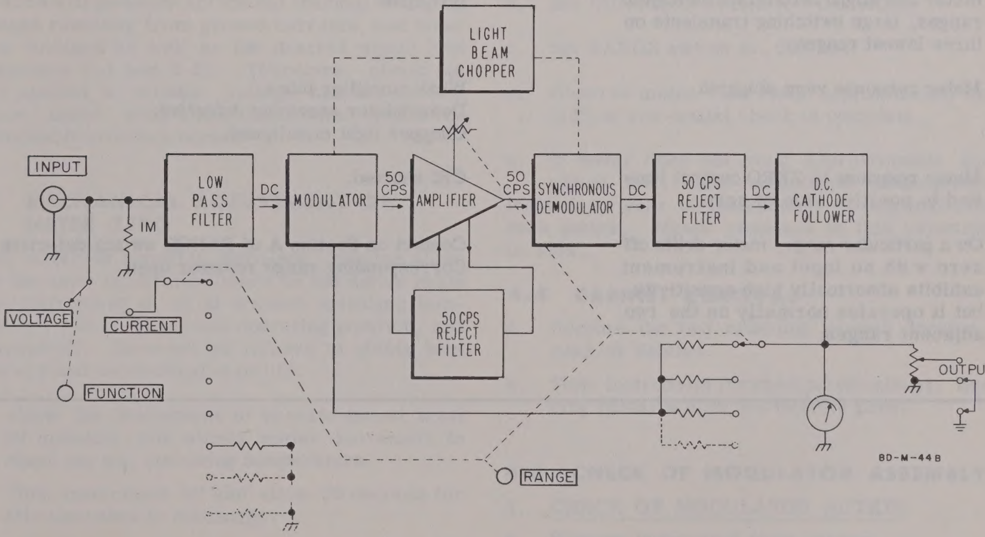


Figure 3-1. Block Diagram of 425A (power-line frequency = 60 cps).

Table 4-1. Trouble-Shooting

SYMPTOM	POSSIBLE CAUSE
Meter fails to respond to input signal, but responds to ZERO control.	Probe assembly defective. INPUT connector defective. Cable from INPUT connector to modular defective. Modulator assembly defective.
Meter fails to respond to either input signal or ZERO control, but responds to bias control.	V1 and/or V2 and/or V3 defective. Modulator assembly defective. Demodulator assembly defective.
Meter fails to respond to either input signal or ZERO control on one range only.	Contact on section D of RANGE switch defective.
Meter driven off negative end of scale.	Loss of B+. V3 heater open.
Meter driven off positive end of scale.	Grid-cathode short in V3B. V5 open.
Excessive noise indicated on meter.	V1 noisy. Poor contact between V1 pins and socket contacts. Noisy breakdown diode, CR1 or CR2.
Instrument operates normally except meter has slight zero offset on higher ranges, large switching transients on three lowest ranges.	Bias adjustment incorrect. R47 open.
Meter response very sluggish.	Weak amplifier tubes. Demodulator assembly defective. Chopper light misaligned.
Meter response to ZERO control limited to positive side of zero.	CR1 shorted.
On a particular range, meter drifts off zero with no input and instrument exhibits abnormally high sensitivity, but it operates normally on the two adjacent ranges.	Contact on Section A of RANGE switch defective. Corresponding range resistor open.

SECTION IV
MAINTENANCE

4-1 GENERAL

A certain amount of trouble-shooting of the 425A can be done visually. Observation of tube heaters, glow of the regulator tubes, incandescent lamps, and meter response to changes of various control and adjustment settings will generally reveal the area of the faulty component if not the component itself. Some symptoms and their possible causes are listed in Table 4-1, and a voltage-resistance chart is included in this section as a trouble-shooting aid in the event you do not find the faulty component visually.

The 425A is basically a simple instrument, and most troubles will be found with a minimum of effort. However, you might lose a great deal of time chasing down psuedo-troubles, particularly if they seem to appear on the most sensitive ranges. These troubles might appear as poor meter calibration, exaggerated zero drift, erroneous readings, etc. The 425A will measure accidental thermal voltages, voltages resulting from ground currents, and other stray voltages as well as the desired signal (see paragraphs 2-1 and 2-2). Therefore, check the 425A against a reliable voltage and/or current source under controlled conditions whenever questionable troubles occur.

4-2 MECHANICAL ADJUSTMENT OF METER ZERO

When meter is properly zero-set, pointer rests over the zero calibration mark on the meter scale when instrument is 1) at normal operating temperature, 2) in its normal operating position, and 3) turned off. Zero-set as follows to obtain best accuracy and mechanical stability:

a. Allow the instrument to operate for at least 20 minutes; this allows meter movement to reach normal operating temperature.

b. Turn instrument off and allow 30 seconds for all capacitors to discharge.

c. Rotate mechanical zero-adjustment screw clockwise until meter pointer is to left of zero and moving upscale toward zero.

d. Continue to rotate adjustment screw clockwise; stop when pointer is right on zero. If pointer overshoots zero, repeat steps c and d.

e. When pointer is exactly on zero, rotate adjustment screw approximately 15 degrees counter-clockwise. This is enough to free adjustment screw from the meter suspension. If pointer moves during this step you must repeat steps c through e.

4-3 PERIODIC CHECK OF CATHODE FOLLOWER BIAS ADJUSTMENT

Check cathode follower bias when you remove 425A from its shipping box. Thereafter, only an occasional check is necessary.

a. Turn instrument ON. Allow 15 minutes to warm-up.

b. Set FUNCTION switch to VOLTAGE.

c. Set RANGE switch to .003 MA.

d. Observe meter. If it reads approximately zero (±5% of end-scale) check is complete.

e. If meter does not read approximately zero, adjust R47, BIAS adjustment potentiometer located on rear of instrument, to approximately zero meter. Meter response to this adjustment is slow.

4-4 CABINET REMOVAL

a. Remove the two retaining screws located on rear of cabinet.

b. Slide instrument forward out of cabinet. Bezel ring remains attached to front panel.

4-5 CHECK OF MODULATOR ASSEMBLY

1. CHECK OF MODULATOR ACTION:

a. Remove instrument from cabinet.

b. Remove cover plate from input-circuit assembly.

c. Set FUNCTION switch to VOLTAGE.

d. Set RANGE switch to 1 MA.

e. Connect probe to a dc signal between 1 and 5 volts.

f. Connect an oscilloscope to point where C4 is connected to circuit board. Connect common lead of oscilloscope to inner chassis. See Fig. 4-2.

g. Energize 425A and observe modulator assembly output on oscilloscope. Figure 4-1 shows a typical waveform on oscilloscope having input impedance of 1 megohm. The waveform should have peak-to-peak amplitude approximately equal to test signal voltage and frequency 5/6 power-line frequency.

h. Disconnect test signal and oscilloscope. Replace cover of input-circuit assembly.

2. CHECK OF INPUT RESISTANCE:

a. Set FUNCTION switch to VOLTAGE.

b. Select a convenient voltage range and check meter zero.

c. Connect probe to a voltage which produces end-scale deflection of meter. Equivalent internal resistance of voltage source must be less than 1000 ohms.

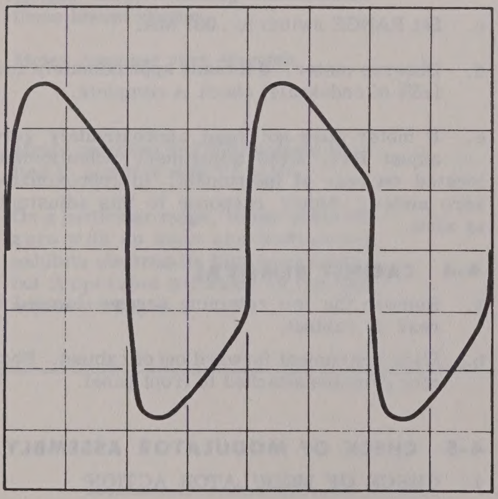


Figure 4-1. Modulator Assembly Output

d. Insert a resistor of know value between voltage source and probe.

e. Note reading on the meter. Determine input resistance of 425A from formula

$$Ri = \frac{Ei}{E - Ei} R,$$

in which Ri is internal resistance of 425A, E is voltage supplied by voltage source, Ei is voltage indicated by 425A with external resistor in series with voltage source, and R is resistance of external resistor. For example, if R = 1 megohm and Ei = 1/2 E, Ri - 1 megohm.

4-6 REPLACEMENT OF MODULATOR ASSEMBLY

Replace the modulator assembly as a unit; do not attempt to repair individual components. See Figure 4-2 and proceed as follows:

a. Disconnect C4 and leads from modulator assembly circuit board; they are connected to the board in the following order, starting from end closest to V1: brown, red, C4, orange, input and pink (to the same point), yellow, black, black, and black. (Note coded letters along edge of board.)

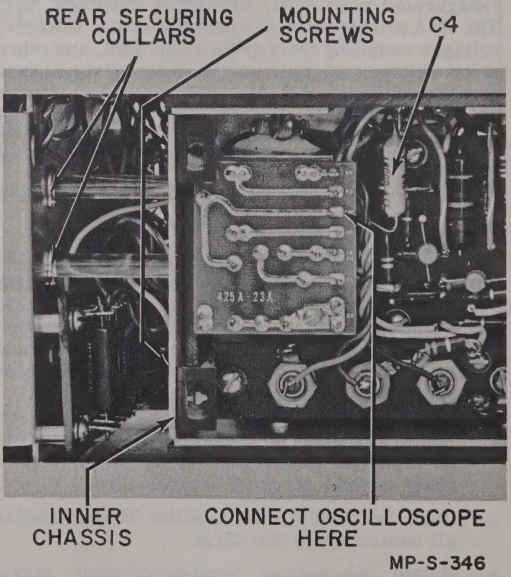


Figure 4-2. Modulator Assembly

b. Remove the two mounting screws which hold assembly in place. These screws are located above and below two plastic rods which enter input-circuit container from rear.

c. Carefully lift out the modulator assembly, Do not force it out, for the plastic rods may hinder its removal. If you must move the rods, spread their rear securing collars and slide them toward rear of instrument.

d. Place new assembly in position and secure it with the two mounting screws. Reposition the plastic rods if they were moved.

e. Connect external leads and C4 to assembly circuit board. Use only rosin-core solder.

NOTE

Use small soldering iron and apply minimum heat when soldering to the circuit board. Clean board carefully and thoroughly when finished. Be sure to remove all solder flux.

----

f. Check new modulator assembly as described in paragraph 4-5.

4-7 CHECK OF DEMODULATOR ASSEMBLY

a. Remove instrument from cabinet.

b. Locate demodulator assembly. It is mounted straight back from the RANGE switch above a resistor board (see figure 4-5).

c. Remove all leads connected to terminals of assembly. The leads are color-coded and connected to terminals in the following order; purple-white (one lead) to terminal farthest from main chassis blue-white (one lead) to middle terminal; and blue (one lead) to terminal nearest main chassis.

d. Connect a dc voltage between 1 and 5 volts across assembly (the two outer terminals).

e. Connect oscilloscope between middle terminal and either outer terminal. Oscilloscope must not present a dc path between its input terminals for this measurement.

f. Energize 425A and observe waveform on oscilloscope. Figure 4-1 shows a typical waveform on oscilloscope having input impedance of 1 megohm. Waveform should have peak-to-peak amplitude approximately equal to test signal voltage and frequency 5/6 power-line frequency.

4-8 ADJUSTMENT OF TWIN-T FILTERS

a. Remove instrument from cabinet.

b. The two filters are contained in a single plug-in unit which is held in place by two retaining screws located at the bottom of either side of unit. Remove unit.

c. Connect a harmonic-free sine wave whose frequency is exactly 5/6 power-line frequency between pins 6 and 8 of the plug base of unit.

d. Connect an oscilloscope or VTVM between pins 7 and 8 of plug base. Compare signal amplitude here with amplitude of the applied signal. If attenuation is approximately 60 db, check of this filter is complete.

e. If there is insufficient attenuation, remove U/shaped cover from unit. Two screws, one on each side secure cover.

f. Alternately adjust R39 and R41 (blue-colored controls) for minimum signal between pins 7 and 8 of base plug.

g. Connect test signal as described in step c between pins 3 and 8 of plug base.

h. Connect oscilloscope or voltmeter between pins 2 and 8 of plug base. Compare signal amplitude here with amplitude of applied signal. If attenuation is approximately 60 db, check of this filter is complete.

i. If there is insufficient attenuation, remove U/shaped cover from unit. Two screws, one on each side secure cover.

j. Alternately adjust R50 and R52 (red-colored controls) for a minimum signal between pins 7 and 8.

4-9 DISCONNECTING INPUT-SHUNTING RESISTOR

On special order, the 425A will be shipped from factory with 1 megohm input-shunting resistor disconnected from the circuit. Input resistance of the modified instrument exceeds 100 megohms on all voltage ranges. Modification can be performed in the field.

NOTE

Calibration of the nine lowest current ranges of modified instrument is altered unless you externally shunt the input with a 1.00 megohm resistor.

Proceed as follows:

a. Remove instrument from cabinet.

b. Remove the cover plate from input-circuit assembly.

c. See Figure 4-3 and locate indicated conductor strip on modulator assembly circuit board. Note that the strip is located between two leads coming from underside of board.

d. Cut the narrow conducting strip at each end. Do not cut into broader section of the conducting material immediately around leads. Use sharp cutting tool such as razor blade.

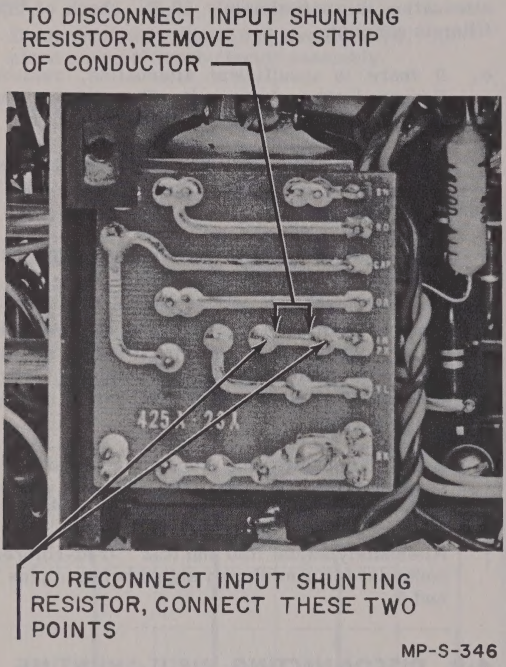

TO DISCONNECT INPUT SHUNTING RESISTOR, REMOVE THIS STRIP OF CONDUCTOR
425A-23X
TO RECONNECT INPUT SHUNTING RESISTOR, CONNECT THESE TWO POINTS
MP-S-346

Figure 4-3. Connection Point of Input-Shunting Resistor

e. Lift out the narrow strip of conducting material. Be careful not to lift any of remaining conducting material off board.

4-10 REPLACEMENT OF INPUT-SHUNTING RESISTOR

The input-shunting resistor remains physically in instrument when modification is made, whether at the factory or in the field. Therefore, the instrument can be restored to standard model at any time. Proceed as follows:

a. Remove instrument from cabinet.

b. Remove the cover plate from input-circuit assembly.

c. See Figure 4-3 and locate indicated points on modulator assembly circuit board.

d. Connect these two points with a piece of copper wire. Solder both ends neatly, using only rosin-core solder.

NOTE

Use a small soldering iron and apply a minimum of heat when soldering to the circuit board. Clean board carefully and thoroughly when finished. Be sure to remove all solder flux.

4-11 METER CALIBRATION

a. Set mechanical adjustment of meter zero (see paragraph 4-2).

b. Turn instrument on. Allow 15 minutes warm-up.

c. Check cathode follower bias adjustment (see paragraph 4-3).

d. Set FUNCTION switch to VOLTAGE.

e. Set RANGE switch to 1 volt range.

f. Connect probe to 1 volt ±1% dc source.

g. Adjust R67, METER CAL to set meter pointer to exactly 1.0. R67 is located just behind meter on the chassis.

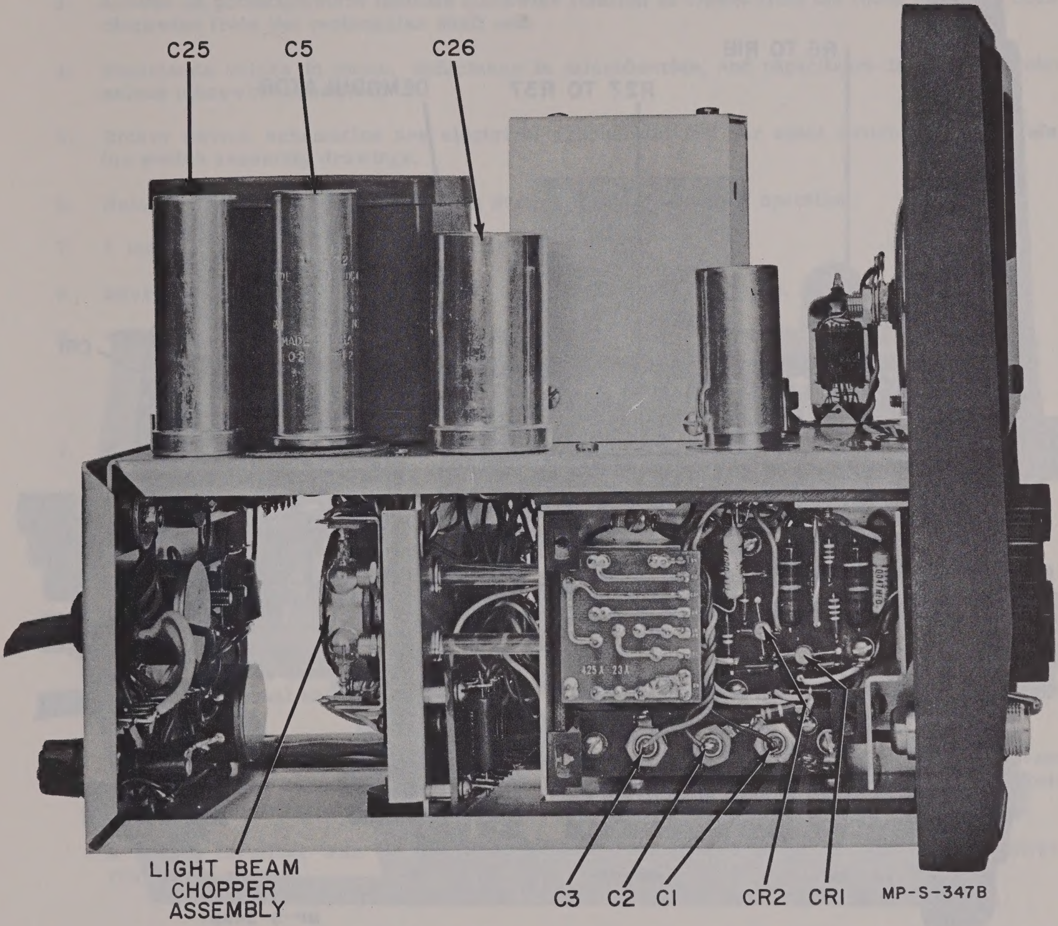


Figure 4-4. Left Side View of Model 425A

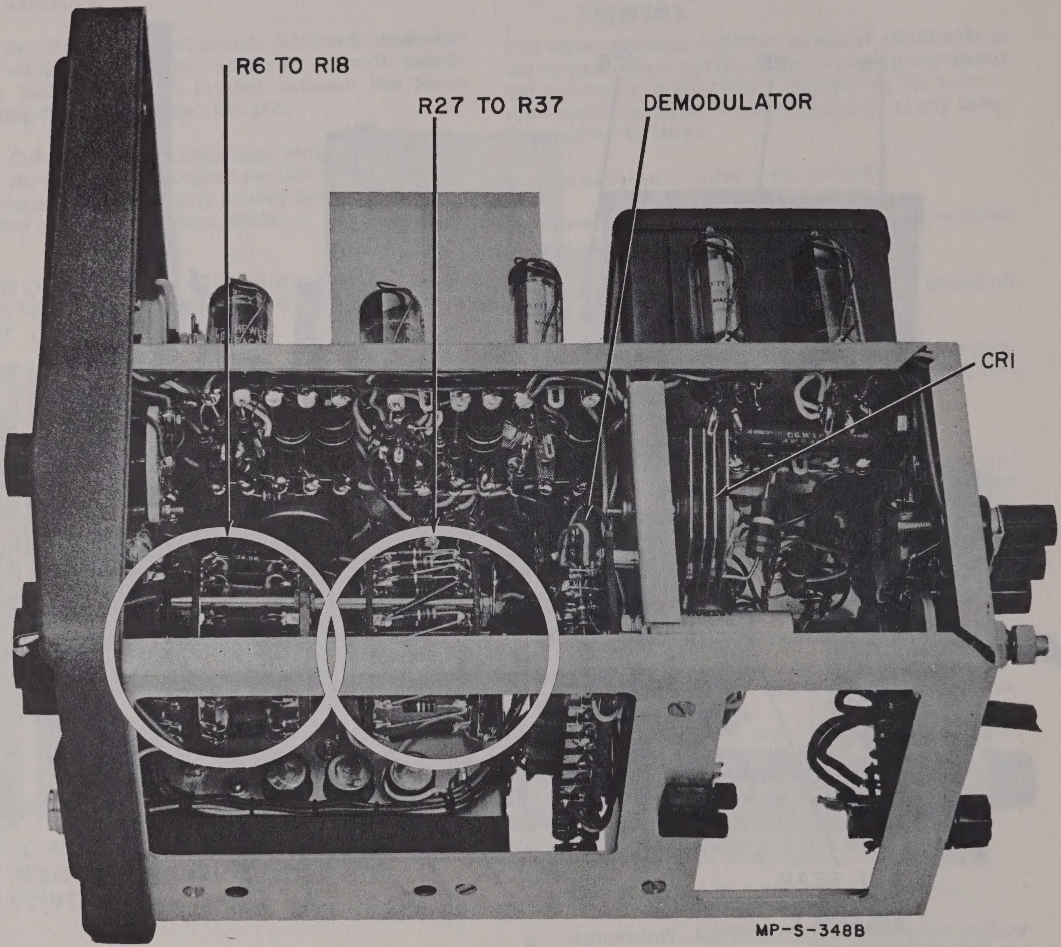


Figure 4-5. Lower Right Side View of Model 425A

SCHEMATIC DIAGRAM NOTES

1. Heavy solid line shows main signal path; heavy dashed line shows control, secondary signal, or feedback path.

2. Heavy box indicates front-panel engraving; light box indicates chassis marking.

3. Arrows on potentiometers indicate clockwise rotation as viewed from the round shaft end, counterclockwise from the rectangular shaft end.

4. Resistance values in ohms, inductance in microhenries, and capacitance in micromicrofarads unless otherwise specified.

5. Rotary switch schematics are electrical representations; for exact switching details refer to the switch assembly drawings.

6. Relays shown in condition prevailing during normal instrument operation.

7. ‡ indicates a selected part. See parts list.

8. Interconnecting parts and assemblies are shown on cable diagram.

9. * Value adjusted at factory. Part may be omitted.

VOLTAGE AND RESISTANCE DIAGRAM NOTES

1. Each tube socket terminal is numbered and lettered to indicate the tube element and pin number, as follows:

   * = no tube element
   H = heater
   K = cathode
   G = control grid
   Sc = screen grid
   Sp = suppressor grid
   Hm = heater mid-tap
   IS = internal shield

   P = plate
   T = target (plate)
   R = reflector or repeller
   A = anode (plate)
   S = spade
   Sh = shield
   NC = no external connection to socket
   Δ = indefinite reading due to circuit (see 2.)

   The numerical subscript to tube-element designators indicates the section of a multiple-section tube; the letter subscript to tube-element designators indicates the functional difference between like elements in the same tube section, such as t for triode and p for pentode.

   A socket terminal with an asterisk may be used as a tie point and may have a voltage and resistance shown.

2. Voltages values shown are for guidance; values may vary from those shown due to tube aging or normal differences between instruments. Resistance values may vary considerably from those shown when the circuit contains potentiometers, crystal diodes, or electrolytic capacitors.

3. Voltage measured at the terminal is shown above the line, resistance below the line; measurements made with an electronic multimeter, from terminal to chassis ground unless otherwise noted.

4. A solid line between socket terminals indicates a connection external to the tube between the terminals; a dotted line between terminals indicates a connection inside the tube. Voltage and resistance are given at only one of the two joined terminals.

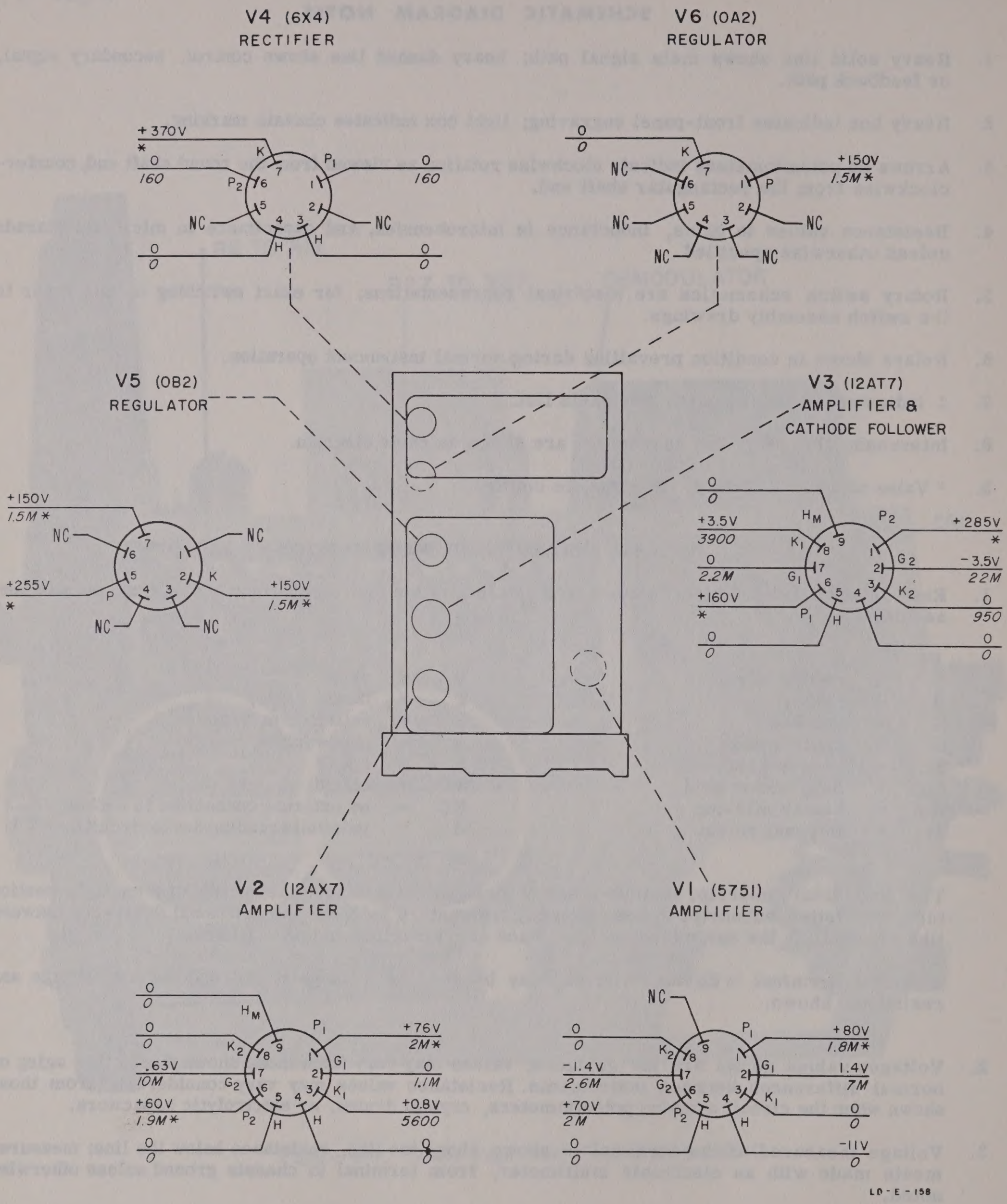


Figure 4-6. Voltage and Resistance Diagram (Viewed from Bottom)

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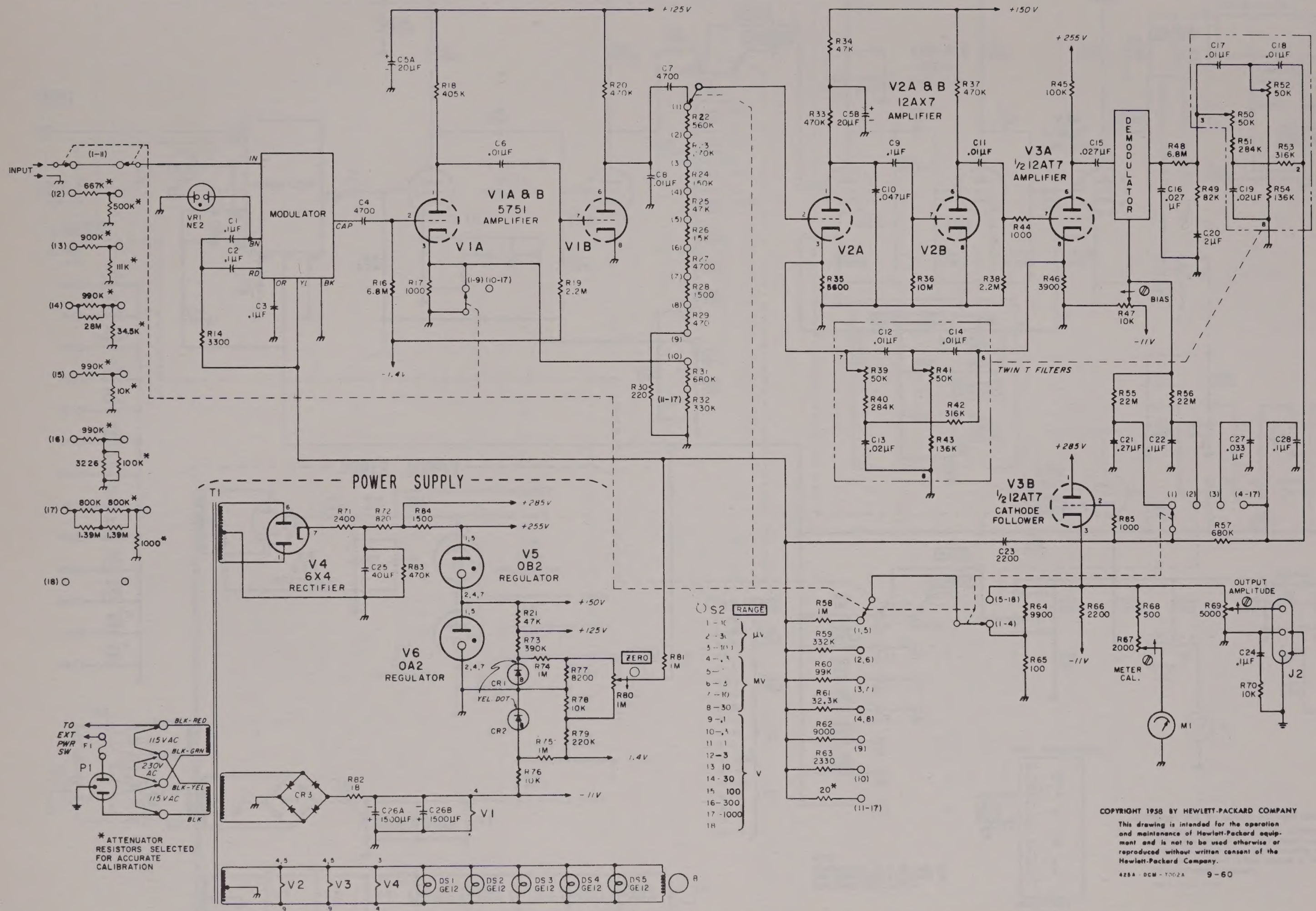

*ATTENUATOR RESISTORS SELECTED FOR ACCURATE CALIBRATION

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425A - DCM - T002A 9-60

hp SPECIFICATION H07 425A DC VOLTMETER

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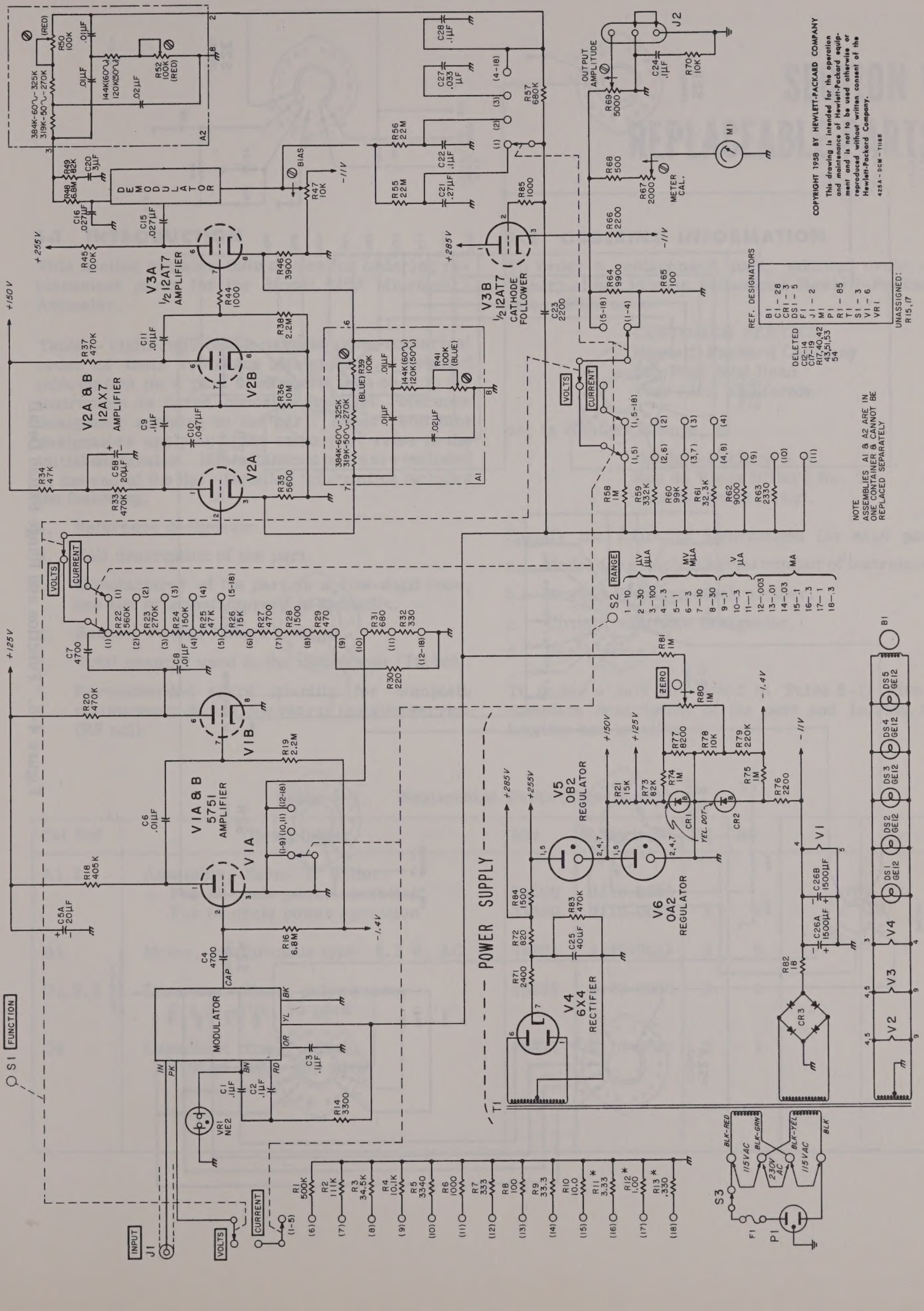

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Figure 4-7. Model 425A Microvolt-Ammeter

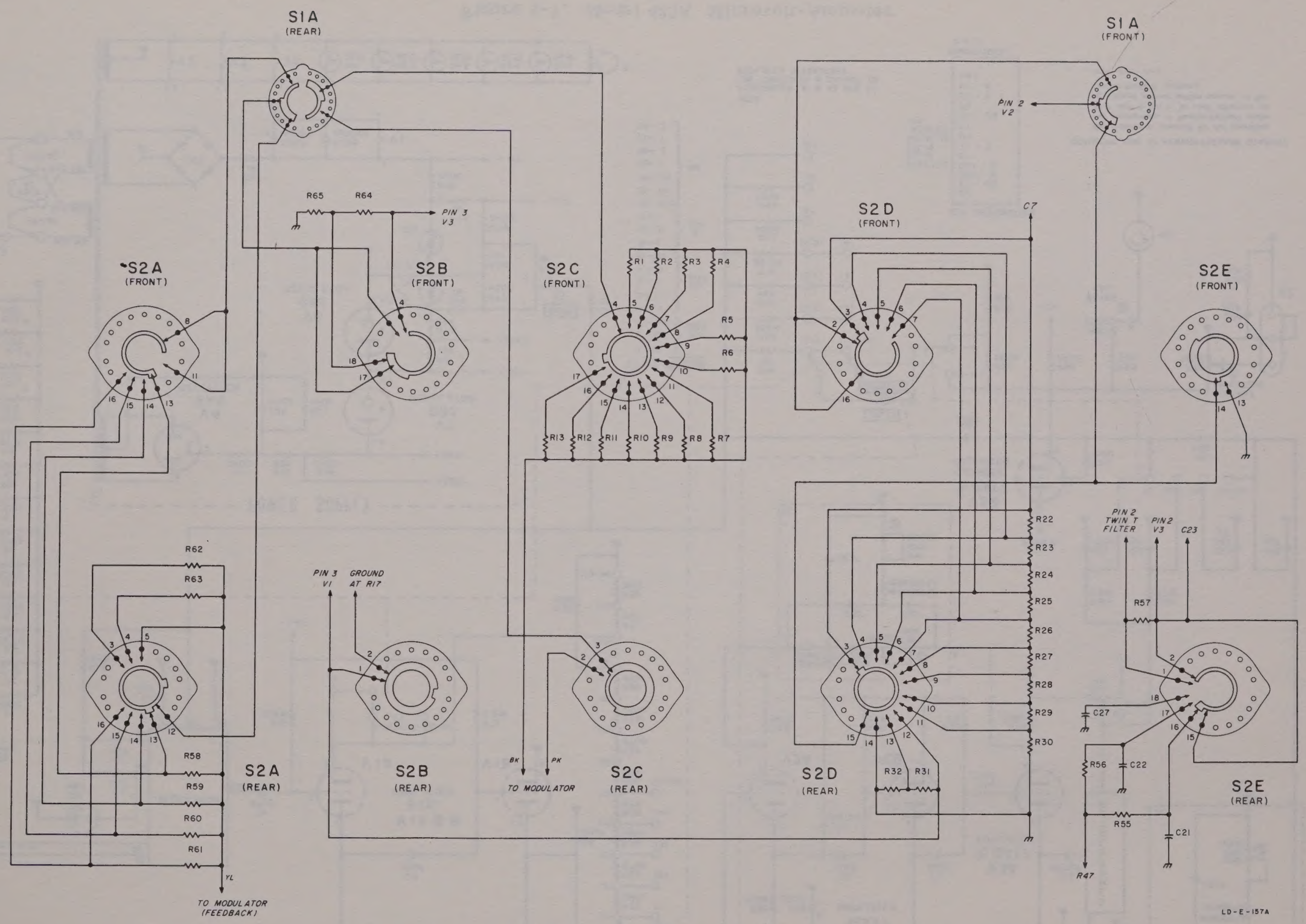

Figure 4-8. Function and Range Switch Detail

SECTION V
REPLACEABLE PARTS

5-1 INTRODUCTION

This section contains information for ordering replacement parts for the Model 425A Microvolt-Ammeter.

Table 5-1 lists replaceable parts in alpha-numerical order of their reference designators. Detailed information on a part used more than once in the instrument is listed opposite the first reference designator applying to the part. Other reference designators applying to the same part refer to the initial designator. Miscellaneous parts are included at the end of the list. Detailed information includes the following:

a. Reference designator.

b. Full description of the part.

c. Manufacturer of the part in a five-digit code; see list of manufacturers in appendix.

d. Hewlett-Packard stock number.

e. Total quantity used in the instrument (TQ col).

f. Recommended spare quantity for complete maintenance during one year of isolated service (RS col).

5-2 ORDERING INFORMATION

To order a replacement part, address order or inquiry either to your authorized Hewlett-Packard sales office or to

CUSTOMER SERVICE
Hewlett-Packard Company
395 Page Mill Road
Palo Alto, California

or, in Western Europe, to

Hewlett-Packard S. A.
Rue du Vieux Billard No. 1
Geneva, Switzerland.

Specify the following information for each part:

a. Model and complete serial number of instrument.

b. Hewlett-Packard stock number.

c. Circuit reference designator.

d. Description.

To order a part not listed in Table 5-1, give a complete description of the part and include its function and location.

Table 5-1. Replaceable Parts (Sheet 1 of 8)

Ckt Ref	Description	Mfr	Stock No.	TQ	RS		
A1,2	Assembly, Twin-"T" Filter:						
	For 50 cycle power operation	71590	9110-0039				
	For 60 cycle power operation	71590	9110-0038	1	1		
B1	Motor, synchronous type: 6.3 V, AC	73061	3140-0013	1	0		
C1,2,3	Capacitor: fixed, polystyrene, 0.1 μf ±10%, 50 vdcw	56289	0170-0030	3	1		
C4	Capacitor: fixed, mylar, 4700 pf ±10%, 400 vdcw	84411	0170-0021	2	1		

Table 5-1. Replaceable Parts (Sheet 2 of 8)

Ckt Ref	Description	Mfr *	hp Stock No.	TQ*	RS*		
C5A, B	Capacitor: fixed, electrolytic, 2 sections 20 μf/sect., 450 vdcw	56289	0180-0012	1	1		
C6	Capacitor: fixed, tubular, 0.01 μf ±20%, 400 vdcw	56289	0160-0054	3	1		
C7	Same as C4						
C8	Same as C6						
C9	Capacitor: fixed, paper, 0.1 μf ±10%, 400 vdcw	56289	0160-0013	1	1		
C10	Capacitor: fixed, paper, 0.047 μf ±10%, 600 vdcw	56289	0160-0005	1	1		
C11	Same as C6						
C12 thru C14	Not assigned						
C15, 16	Capacitor: fixed, paper, 0.027 μf ±10%, 600 vdcw	56289	0160-0026	2	1		
C17 thru C19	Not assigned						
C20	Capacitor: fixed, paper, 2 μf ±20%, 200 vdcw	82376	0160-0030	1	1		
C21	Capacitor: fixed, paper, 0.27 μf ±10%, 200 vdcw	56289	0160-0039	1	1		
C22	Capacitor: fixed, mylar, 0.1 μf ±5%, 200 vdcw	84411	0170-0019	1	1		
C23	Capacitor: fixed, paper, 2200 pf ±10%, 600 vdcw	56289	0160-0007	1	1		
C24	Capacitor: fixed, mylar, 0.1 μf ±20%, 600 vdcw	09134	0170-0022	2	1		
C25	Capacitor: fixed, electrolytic, 40 μf, 450 vdcw	56289	0180-0024	1	1		
C26A, B	Capacitor: fixed, electrolytic, 2 sections 1500 μf/sect., 15 vdcw	56289	0180-0028	1	1		
C27	Capacitor: fixed, paper, 0.033 μf ±10%, 600 vdcw	56289	0160-0004	1	1		

* See introduction to this section

Table 5-1. Replaceable Parts (Sheet 3 of 8)

Ckt Ref	Description	Mfr *	hp Stock No.	TQ*	RS*	
C28	Same as C24					
CR1, 2	Diode, breakdown	28480	G-29A-74	2	2	
CR3	Rectifier, metallic	81483	1882-0005	1	1	
DS1 thru DS5	Lamp, incandescent: 6-8V, 2 pin base, #12	24455	2140-0012	5	5	
F1	Fuse, cartridge: 1 amp, slow-blow (for 115V operation)	71400	2110-0007	1	10	
	Fuse, cartridge: 1/2 amp, slow-blow (for 230V operation)	71400	2110-0008			
J1	Connector, triaxial panel jack: input receptacle	91737	1250-0039	1	1	
J2	Connector Assembly					
	binding post & ground link	28480	G-76J	1	1	
	binding post: red	28480	AC-10D	2	1	
	binding post: black, (rack mount only)	28480	AC-10C	1	0	
M1	Meter	28480	G-81E	1	1	
P1	Power cord	70903	8120-0050	1	1	
R1	Resistor: fixed, metal film, 500,000 ohms ±1/2%, 1/2 W	65092	0757-0015	1	1	
R2	Resistor: fixed, metal film, 111,000 ohms ±1/2%, 1/2 W	65092	0757-0013	1	1	
R3	Resistor: fixed, metal film, 34,500 ohms ±1/2%, 1/2 W	65092	0757-0008	1	1	
R4	Resistor: fixed, wirewound, 10,100 ohms (brown)	28480	425A-26A	1	0	
R5	Resistor: fixed, wirewound, 3,340 ohms (yellow)	28480	425A-26D	1	0	
R6	Resistor: fixed 1000 ohms (green/white)	28480	425A-26F	1	0	
R7	Resistor: fixed, wirewound, 333 ohms (blue)	28480	425A-26G	1	0	
R8	Resistor: fixed 100 ohms (purple)	28480	425A-26H	2	0	
R9	Resistor: fixed, wirewound, 33.3 ohms (grey)	28480	425A-26I	1	0	

* See introduction to this section

Table 5-1. Replaceable Parts (Sheet 4 of 8)

Ckt Ref	Description	Mfr *	hp Stock No.	TQ*	RS*		
R10	Resistor: fixed 10.0 ohms (white)	28480	425A-26J	1	0		
R11	Resistor: fixed, wirewound, 3.26 ohms (black)	28480	425A-26K	1	0		
R12	Resistor: fixed .930 ohms (pink)	28480	425A-26L	1	0		
R13	Resistor: fixed, wirewound, .260 ohms (pink/white)	28480	425A-26M	1	0		
R14	Resistor: fixed, composition, 3300 ohms ±10%, 1/2 W	01121	0687-3321	1	1		
R15	Not assigned						
R16	Resistor: fixed, composition, 6.8 megohms ±10%, 1/2 W	01121	0687-6851	2	1		
R17	Not assigned						
R18	Resistor: fixed, deposited carbon, 405,000 ohms ±1%, 1/2 W	19701	0727-0240	1	1		
R19	Resistor: fixed, composition, 2.2 megohms ±10%, 1/2 W	01121	0687-2251	2	1		
R20	Resistor: fixed, composition, 470,000 ohms ±10%, 1/2 W	01121	0687-4741	4	1		
R21	Resistor: fixed, composition, 15,000 ohms ±10%, 1/2 W	01121	0687-1531	2	1		
R22	Resistor: fixed, composition, 560,000 ohms ±10%, 1/2 W	01121	0687-5641	1	1		
R23	Resistor: fixed, composition, 270,000 ohms ±10%, 1/2 W	01121	0687-2741	1	1		
R24	Resistor: fixed, composition, 150,000 ohms ±10%, 1/2 W	01121	0687-1541	1	1		
R25	Resistor: fixed, composition, 47,000 ohms ±10%, 1/2 W	01121	0687-4731	2	1		
R26	Same as R21						
R27	Resistor: fixed, composition, 4700 ohms ±10%, 1/2 W	01121	0687-4721	1	1		
R28	Resistor: fixed, composition, 1500 ohms ±10%, 1/2 W	01121	0687-1521	1	1		

* See introduction to this section

Table 5-1. Replaceable Parts (Sheet 5 of 8)

Ckt Ref	Description	Mfr *	hp Stock No.	TQ*	RS*		
R29	Resistor: fixed, composition, 470 ohms ±10%, 1/2 W	01121	0687-4711	1	1		
R30	Resistor: fixed, composition, 220 ohms ±10%, 1/2 W	01121	0687-2211	1	1		
R31	Resistor: fixed, composition, 680 ohms ±10%, 1/2 W	01121	0687-6811	1	1		
R32	Resistor: fixed, composition, 330 ohms ±10%, 1/2 W	01121	0687-3311	1	1		
R33	Same as R20						
R34	Same as R25						
R35	Resistor: fixed, composition, 5600 ohms ±10%, 1/2 W	01121	0687-5621	1	1		
R36	Resistor: fixed, composition, 10 megohms ±10%, 1/2 W	01121	0687-1061	1	1		
R37	Same as R20						
R38	Same as R19						
R39	Resistor: variable, part of A1						
R40	Not assigned						
R41	Resistor: variable, part of A1						
R42, 43	Not assigned						
R44	Resistor: fixed, composition, 1000 ohms ±10%, 1/2 W	01121	0687-1021	2	1		
R45	Resistor: fixed, composition, 100,000 ohms ±10%, 1/2 W	01121	0687-1041	1	1		
R46	Resistor: fixed, composition, 3900 ohms ±10%, 1/2 W	01121	0687-3921	1	1		
R47	Resistor: variable, wirewound, 10,000 ohms	11237	2100-0053	1	1		
R48	Same as R16						
R49	Resistor: fixed, composition, 82,000 ohms ±10%, 1/2 W	01121	0687-8231	2	1		
R50	Resistor: variable, part of A2						

* See introduction to this section

Table 5-1. Replaceable Parts (Sheet 6 of 8)

Ckt Ref	Description	Mfr *	hp Stock No.	TQ*	RS*	
R51	Not assigned					
R52	Resistor: variable, part of A2					
R53,54	Not assigned					
R55,56	Resistor: fixed, composition, 22 megohms ±10%, 1/2 W	01121	0687-2261	2	1	
R57	Resistor: fixed, composition, 680,000 ohms ±10%, 1/2 W	01121	0687-6841	1	1	
R58	Resistor: fixed, metal film 1.0 megohm ±1%, 1/2 W	65092	0757-0017	1	1	
R59	Resistor: fixed, metal film 332,000 ohms ±1%, 1/2 W	65092	0757-0014	1	1	
R60	Resistor: fixed, metal film, 99,000 ohms ±1%, 1/2 W	65092	0757-0010	1	1	
R61	Resistor: fixed, metal film, 32,300 ohms ±1%, 1/2 W	65092	0757-0007	1	1	
R62	Resistor: fixed, wirewound, 9000 ohms ±1/2%, 1/2 W (orange)	28480	425A-26C	1	1	
R63	Resistor: fixed, wirewound, 2330 ohms ±1/2%, 1/2 W (green)	28480	425A-26E	1	1	
R64	Resistor: fixed, wirewound, 9900 ohms ±1/2%, 1/2 W (red)	28480	425A-26B	1	1	
R65	Same as R8					
R66	Resistor: fixed, composition, 2200 ohms ±10%, 1/2 W	01121	0687-2221	2	1	
R67	Resistor: variable, wirewound, 2000 ohms ±10%, 2 W	11237	2100-0005	1	1	
R68	Resistor: fixed, deposited carbon, 500 ohms ±1%, 1/2 W	19701	0727-0077	1	1	
R69	Resistor: variable, wirewound, 5000 ohms ±10%, 2 W	11237	2100-0006	1	1	
R70	Resistor: fixed, composition, 10,000 ohms ±10%, 1/2 W	01121	0687-1031	1	1	
R71	Resistor: fixed, metal film 2400 ohms ±5%, 4 W	07115	0770-0002	1	1	

* See introduction to this section

Table 5-1. Replaceable Parts (Sheet 7 of 8)

Ckt Ref	Description	Mfr *	hp Stock No.	TQ*	RS*
R72	Resistor: fixed, composition, 820 ohms ±10%, 1/2 W	01121	0693-8211	1	1
R73	Same as R49				
R74, 75	Resistor: fixed, composition, 1 megohm ±5%, 1/2 W	01121	0686-1055	2	1
R76	Same as R66				
R77	Resistor: fixed, composition, 8200 ohms ±5%, 1/2 W	01121	0686-8225	1	1
R78	Resistor: fixed, composition, 10,000 ohms ±5%, 1/2 W	01121	0686-1035	1	1
R79	Resistor: fixed, composition, 220,000 ohms ±5%, 1/2 W	01121	0686-2245	1	1
R80	Resistor: variable, composition, linear taper, 1 megohm ±30%	71590	2100-0074	1	1
R81	Resistor: fixed, composition, 1 megohm ±10%, 1/2 W	01121	0687-1051	1	1
R82	Resistor: fixed, composition, 18 ohms ±10%, 2 W	01121	0693-1801	1	1
R83	Same as R20				
R84	Resistor: fixed, composition, 1500 ohms ±10%, 2 W	01121	0693-1521	1	1
R85	Same as R44				
S1	Switch, function: rotary	76854	3100-0157	1	1
S2	Switch, rotary: less components	76854	3100-0158		
	Range Switch Assembly	28480	425A-19A	1	1
S3	Switch, toggle: SPST	04009	3101-0001	1	1
T1	Transformer, power	28480	9100-0094	1	1
V1	Tube, electron: 5751WA	80131	1932-0033	1	1
V2	Tube, electron: 12AX7	80131	1932-0030	1	1
V3	Tube, electron: 12AT7	80131	1932-0027	1	1

* See introduction to this section

Table 5-1. Replaceable Parts (Sheet 8 of 8)

Ckt Ref	Description	Mfr *	hp Stock No.	TQ*	RS*
V4	Tube, electron: 6X4	80131	1930-0016	1	1
V5	Tube, electron: OB2	80131	1940-0007	1	1
V6	Tube, electron: OA2	80131	1940-0004	1	1
VR1	Lamp, neon: 1/25 W, NE-2	24455	2140-0008	1	1
	MISCELLANEOUS				
	Cable, probe	28480	425A-21A-95B		
	Chopper Assembly: includes B1, lamps	28480	425A-97A	1	1
	Demodulator, assembly	28480	425A-23B	1	0
	Fuseholder	75915	1400-0084	1	1
	Insulator	28480	AC-54D	16	0
	Input Amplifier Assembly	28480	425A-58A	1	0
	Insulator	28480	AC-54B	2	0
	Jewel	72765	1450-0020	1	0
	Knob: (rack model)	28480	G-74C	1	0
	Knob: (cabinet model)	28480	G-74D	1	0
	Knob: (rack model)	28480	G-74N	1 2	0
	Lampholder	72765	1450-0022	5	1
	Probe Assembly (complete)	28480	425A-21A	1	1
	Probe, tip and jaw assembly only	28480	425A-21A-95		

* See introduction to this section

APPENDIX
CODE LIST OF MANUFACTURERS (Sheet 1 of 2)

The following code numbers are from the Federal Supply Code for Manufacturers Cataloging Handbooks H4-1 (Name to Code) and H4-2 (Code to Name) and their latest supplements. The date of revision and the date of the supplements used appear at the bottom of each page. Alphabetical codes have been arbitrarily assigned to suppliers not appearing in the H4 handbooks.

CODE NO.	MANUFACTURER	ADDRESS
00334	Humidial Co.	Colton, Calif.
00335	Westrex Corp.	New York, N.Y.
00373	Garlock Packing Co., Electronic Products Div.	Camden, N.J.
00656	Aerovox Corp.	New Bedford, Mass.
00779	Amp, Inc.	Harrisburg, Pa.
00781	Aircraft Radio Corp.	Boonton, N.J.
00853	Sangamo Electric Co., Cap. Div.	Marion, Ill.
00866	Goe Engineering Co.	Los Angeles, Calif.
00891	Carl E. Holmes Corp.	Los Angeles, Calif.
01121	Allen Bradley Co.	Milwaukee, Wis.
01255	Litton Industries, Inc.	Beverly Hills, Calif.
01281	Pacific Semiconductors, Inc.	Culver City, Calif.
01295	Texas Instruments, Inc. Semiconductor Components Div.	Dallas, Texas
01349	The Alliance Mfg. Co.	Alliance, Ohio
01561	Chassi-Trak Corp.	Indianapolis, Ind.
01961	Pulse Engineering Co.	Santa Clara, Calif.
02114	Ferroxcube Corp. of America	Saugerties, N.Y.
02286	Cole Mfg. Co.	Palo Alto, Calif.
02660	Amphenol Electronics Corp.	Chicago, Ill.
02735	Radio Corp. of America Semiconductor and Materials Div.	Somerville, N.J.
02777	Hopkins Engineering Co.	San Fernando, Calif.
03508	G.E. Semiconductor Products Dept.	Syracuse, N.Y.
03705	Apex Machine & Tool Co.	Dayton, Ohio
03797	Eldema Corp.	El Monte, Calif.
03877	Transitron Electronic Corp.	Wakefield, Mass.
03954	Air Marine Motors, Inc.	Los Angeles, Calif.
04009	Arrow, Hart and Hegeman Elect. Co.	Hartford, Conn.
04062	Elmenco Products Co.	New York, N.Y.
04222	Hi-Q Division of Aerovox	Myrtle Beach, S.C.
04651	Special Tube Operations of Sylvania Electronic Systems	Mountain View, Calif.
04713	Motorola, Inc., Semiconductor Prod. Div.	Phoenix, Arizona
04732	Filtron Co., Inc. Western Division	Culver City, Calif.
04777	Automatic Electric Sales Corp.	Northlake, Ill.
05006	Twentieth Century Plastics, Inc.	Los Angeles, Calif.
05277	Westinghouse Electric Corp., Semi-Conductor Dept.	Youngwood, Pa.
05624	Barber Colman Co.	Rockford, Ill.
05783	Stewart Engineering Co.	Soquel, Calif.
06004	The Bassick Co.	Bridgeport, Conn.
06812	Torrington Mfg. Co., West. Div.	Van Nuys, Calif.
07115	Corning Glass Works Electronic Components Dept.	Bradford, Pa.
07137	Transistor Electronics Corp.	Minneapolis, Minn.
07261	Avnet Corp.	Los Angeles, Calif.
07263	Fairchild Semiconductor Corp.	Mountain View, Calif.
07933	Rheem Semiconductor Corp.	Mountain View, Calif.
07980	Boonton Radio Corp.	Boonton, N.J.
08358	Burgess Battery Co.	Niagara Falls, Ontario, Canada
08718	Cannon Electric Co. Phoenix Div.	Phoenix, Ariz.
08792	CBS Electronics Semiconductor Operations, Div. of C.B.S. Inc.	Lowell, Mass.
09134	Texas Capacitor Co.	Houston, Texas
09250	Electro Assemblies, Inc.	Chicago, Ill.
09569	Mallory Battery Co. of Canada, Ltd.	Toronto, Ontario, Canada
10411	Ti-Tal, Inc.	Berkeley, Calif.
10646	Carborundum Co.	Niagara Falls, N.Y.
11236	CTS of Berne, Inc.	Berne, Ind.
11237	Chicago Telephone of California, Inc.	So. Pasadena, Calif.
11264	Dymec, Inc.	Palo Alto, Calif.
12697	Clarostat Mfg. Co.	Dover, N.H.
14655	Cornell Dubilier Elec. Corp.	So. Plainfield, N.J.
15909	The Daven Co.	Livingston, N.J.
16758	Delco Radio Div. of G. M. Corp.	Kokomo, Ind.
18873	E. I. DuPont and Co., Inc.	Wilmington, Del.
19315	Eclipse Pioneer, Div. of Bendix Aviation Corp.	Teterboro, N.J.
19500	Thomas A. Edison Industries, Div. of McGraw-Edison Co.	West Orange, N.J.
19701	Electra Manufacturing Co.	Kansas City, Mo.
20183	Electronic Tube Corp.	Philadelphia, Pa.
21520	Fansteel Metallurgical Corp.	No. Chicago, Ill.
21335	The Fafnir Bearing Co.	New Britain, Conn.
21964	Fed. Telephone and Radio Corp.	Clifton, N.J.
24446	General Electric Co.	Schenectady, N.Y.
24455	G. E., Lamp Division	Nela Park, Cleveland, Ohio
24655	General Radio Co.	West Concord, Mass.
26462	Grobet File Co. of America, Inc.	Carlstadt, N.J.
26992	Hamilton Watch Co.	Lancaster, Pa.
28480	Hewlett-Packard Co.	Palo Alto, Calif.
33173	G. E. Receiving Tube Dept.	Owensboro, Ky.
35434	Lectrohm Inc.	Chicago, Ill.
37942	P. R. Mallory & Co., Inc.	Indianapolis, Ind.
39543	Mechanical Industries Prod. Co.	Akron, Ohio
40920	Miniature Precision Bearings, Inc.	Keene, N.H.
42190	Muter Co.	Chicago, Ill.
43990	C. A. Norgren Co.	Englewood, Colo.
44655	Ohmite Mfg. Co.	Skokie, Ill.
47904	Polaroid Corp.	Cambridge, Mass.
48620	Precision Thermometer and Inst. Co.	Philadelphia, Pa.
49956	Raytheon Mfg. Co.	Waltham, Mass.
54294	Shallcross Mfg. Co.	Selma, N.C.
55026	Simpson Electric Co.	Chicago, Ill.
55933	Sonotone Corp.	Elmsford, N.Y.
55938	Sorenson & Co., Inc.	So. Norwalk, Conn.
56137	Spaulding Fibre Co., Inc.	Tonawanda, N.Y.
56289	Sprague Electric Co.	North Adams, Mass.
59446	Telex, Inc.	St. Paul, Minn.
61775	Union Switch and Signal, Div. of Westinghouse Air Brake Co.	Pittsburgh, Pa.
62119	Universal Electric Co.	Owosso, Mich.
64959	Western Electric Co., Inc.	New York, N.Y.
65092	Weston Inst. Div. of Daystrom, Inc.	Newark, N.J.
66346	Wollensak Optical Co.	Rochester, N.Y.
70119	Advance Electric and Relay Co.	Burbank, Calif.
70276	Allen Mfg. Co.	Hartford, Conn.
70309	Allied Control Co., Inc.	New York, N.Y.
70485	Atlantic India Rubber Works, Inc.	Chicago, Ill.
70563	Amperite Co., Inc	New York, N.Y.
70903	Belden Mfg. Co.	Chicago, Ill.
70998	Bird Electronic Corp.	Cleveland, Ohio
71002	Birnbach Radio Co.	New York, N.Y.
71218	Bud Radio Inc.	Cleveland, Ohio
71286	Camloc Fastener Corp.	Paramus, N.J.
71313	Allen D. Cardwell Electronic Prod. Corp	Plainville, Conn.
71400	Bussmann Fuse Div. of McGraw-Edison Co.	St. Louis, Mo.
71450	Chicago Telephone Supply Co.	Elkhart, Ind.
71468	Cannon Electric Co.	Los Angeles, Calif.
71471	Cinema Engineering Co.	Burbank, Calif.
71482	C. P. Clare & Co.	Chicago, Ill.
71590	Centralab Div. of Globe Union Inc.	Milwaukee, Wis.
71700	The Cornish Wire Co.	New York, N.Y.
71744	Chicago Miniature Lamp Works	Chicago, Ill.
71753	A. O. Smith Corp., Crowley Div.	West Orange, N.J.
71785	Cinch Mfg. Corp.	Chicago, Ill.
71984	Dow Corning Corp.	Midland, Mich.
72136	Electro Motive Mfg. Co., Inc.	Willimantic, Conn.
72354	John E. Fast & Co.	Chicago, Ill.
72619	Dialight Corp.	Brooklyn, N.Y.
72656	General Ceramics Corp.	Keasbey, N.J.
72758	Girard-Hopkins	Oakland, Calif.
72765	Drake Mfg. Co.	Chicago, Ill.
72825	Hugh H. Eby Inc.	Philadelphia, Pa.
72928	Gudeman Co.	Chicago, Ill.
72982	Erie Resistor Corp.	Erie, Pa.
73061	Hansen Mfg. Co., Inc.	Princeton, Ind.
73138	Helipot Div. of Beckman Instruments, Inc.	Fullerton, Calif.
73293	Hughes Products Div. of Hughes Aircraft Co.	Newport Beach, Calif.
73445	Amperex Electronic Co., Div. of North American Phillips Co., Inc.	Hicksville, N.Y.
73506	Bradley Semiconductor Corp.	New Haven, Conn.
73559	Carling Electric, Inc.	Hartford, Conn.
73682	George K. Garrett Co., Inc.	Philadelphia, Pa.
73743	Fischer Special Mfg. Co.	Cincinnati, Ohio
73793	The General Industries Co.	Elyria, Ohio
73905	Jennings Radio Mfg. Co.	San Jose, Calif.
74455	J. H. Winns, and Sons	Winchester, Mass.
74861	Industrial Condenser Corp.	Chicago, Ill.
74868	Industrial Products Co.	Danbury, Conn.
74970	E. F. Johnson Co.	Waseca, Minn.
75042	International Resistance Co.	Philadelphia, Pa.
75173	Jones, Howard B., Division of Cinch Mfg. Corp.	Chicago, Ill.
75378	James Knights Co.	Sandwich, Ill.
75382	Kulka Electric Mfg. Co., Inc.	Mt. Vernon, N.Y.
75818	Lenz Electric Mfg. Co.	Chicago, Ill.
75915	Littelfuse Inc.	Des Plaines, Ill.
76005	Lord Mfg. Co.	Erie, Pa.
76210	C. W. Marwedel	San Francisco, Calif.
76433	Micamold Electronic Mfg. Corp.	Brooklyn, N.Y.

From: F.S.C. Handbook Supplements
H4-1 Dated Oct. 1960
H4-2 Dated Oct. 1960

ESI 9/62

APPENDIX
CODE LIST OF MANUFACTURERS (Sheet 2 of 2)

CODE NO.	MANUFACTURER	ADDRESS
76487	James Millen Mfg. Co., Inc.	Malden, Mass.
76530	Monadnock Mills	San Leandro, Calif.
76545	Mueller Electric Co.	Cleveland, Ohio
76854	Oak Manufacturing Co.	Chicago, Ill.
77068	Bendix Corp., Bendix Pacific Div.	No. Hollywood, Calif.
77221	Phaostron Instrument and Electronic Co.	South Pasadena, Calif.
77342	Potter and Brumfield, Inc.	Princeton, Ind.
77630	Radio Condenser Co.	Camden, N.J.
77634	Radio Essentials Inc.	Mt. Vernon, N.Y.
77638	Radio Receptor Co., Inc.	Brooklyn, N.Y.
77764	Resistance Products Co.	Harrisburg, Pa.
78283	Signal Indicator Corp.	New York, N.Y.
78471	Tilley Mfg. Co.	San Francisco, Calif.
78488	Stackpole Carbon Co.	St. Marys, Pa.
78790	Transformer Engineers	Pasadena, Calif.
78947	Ucinite Co.	Newtonville, Mass.
79142	Veeder Root, Inc.	Hartford, Conn.
79251	Wenco Mfg. Co.	Chicago, Ill.
79963	Zierick Mfg. Corp.	New Rochelle, N.Y.
80130	Times Facsimile Corp.	New York, N.Y.
80131	Electronic Industries Association Any brand tube meeting EIA standards	Washington, D.C.
80248	Oxford Electric Corp.	Chicago, Ill.
80411	Acro Manufacturing Co.	Columbus, Ohio
80486	All Star Products Inc.	Defiance, Ohio
80583	Hammerlund Co., Inc.	New York, N.Y.
80640	Stevens, Arnold, Co., Inc.	Boston, Mass.
81030	International Instruments, Inc.	New Haven, Conn.
81415	Wilkor Products, Inc.	Cleveland, Ohio
81453	Raytheon Mfg. Co., Industrial Tube Division	Quincy, Mass.
81483	International Rectifier Corp.	El Segundo, Calif.
81860	Barry Controls, Inc.	Watertown, Mass.
82042	Carter Parts Co.	Skokie, Ill.
82142	Jeffers Electronics Division of Speer Carbon Co.	Du Bois, Pa.
82170	Allen B. DuMont Labs., Inc.	Clifton, N.J.
82209	Maguire Industries, Inc.	Greenwich, Conn.
82219	Sylvania Electric Prod. Inc., Electronic Tube Div.	Emporium, Pa.
82376	Astron Co.	East Newark, N.J.
82389	Switchcraft, Inc.	Chicago, Ill.
82647	Texas Instruments, Inc., Metals and Controls Div., Spencer Products	Attleboro, Mass.
82866	Research Products Corp.	Madison, Wis.
82893	Vector Electronic Co.	Glendale, Calif.
83148	Electro Cords Co.	Los Angeles, Calif.
83186	Victory Engineering Corp.	Union, N.J.
83298	Bendix Corp., Red Bank Div.	Red Bank, N.J.
83594	Burroughs Corp., Electronic Tube Div.	Plainfield, N.J.
83777	Model Eng. and Mfg., Inc.	Huntington, Ind.
83821	Loyd Scruggs Co.	Festus, Mo.
84171	Arco Electronics, Inc.	New York, N.Y.
84396	A. J. Glesener Co., Inc.	San Francisco, Calif.
84411	Good All Electric Mfg. Co.	Ogallala, Neb.
84970	Sarkes Tarzian, Inc.	Bloomington, Ind.
85474	R. M. Bracamonte & Co.	San Francisco, Calif.
85660	Koiled Kords, Inc.	New Haven, Conn.
85911	Seamless Rubber Co.	Chicago, Ill.
86684	Radio Corp. of America, RCA Electron Tube Div.	Harrison, N.J.
88140	Cutler-Hammer, Inc.	Lincoln, Ill.
89473	General Electric Distributing Corp.	Schenectady, N.Y.
90179	U.S. Rubber Co., Mechanical Goods Div.	Passaic, N.J.
90970	Bearing Engineering Co.	San Francisco, Calif.
91418	Radio Materials Co.	Chicago, Ill.
91506	Augat Brothers, Inc.	Attleboro, Mass.
91637	Dale Products, Inc.	Columbus, Neb.
91662	Elco Corp.	Philadelphia, Pa.
91737	Gremar Mfg. Co., Inc.	Wakefield, Mass.
91827	K F Development Co.	Redwood City, Calif.
91929	Micro-Switch Div. of Minneapolis Honeywell Regulator Co.	Freeport, Ill.
92196	Universal Metal Products, Inc.	Bassett Puente, Calif.
93332	Sylvania Electric Prod. Inc., Semiconductor Div.	Woburn, Mass.
93369	Robbins and Myers, Inc.	New York, N.Y.
93410	Stevens Mfg. Co., Inc.	Mansfield, Ohio
93983	Insuline-Van Norman Ind., Inc. Electronic Division	Manchester, N.H.
94144	Raytheon Mfg. Co., Receiving Tube Div.	Quincy, Mass.
94145	Raytheon Mfg. Co., Semiconductor Div.	Newton, Mass.
94148	Scientific Radio Products, Inc.	Loveland, Colo.
94154	Tung-Sol Electric, Inc.	Newark, N.J.
94197	Curtiss-Wright Corp., Electronics Div.	Carlstadt, N.J.
94310	Tru Ohm Prod. Div. of Model Engineering and Mfg. Co.	Chicago, Ill.
95236	Allies Products Corp.	Miami, Fla.
95238	Continental Connector Corp.	Woodside, N.Y.
95263	Leecraft Mfg. Co., Inc.	New York, N.Y.
95265	National Coil Co.	Sheridan, Wyo.
95987	Weckesser Co.	Chicago, Ill.
96067	Huggins Laboratories	Sunnyvale, Calif.
96095	Hi-Q Division of Aerovox	Olean, N.Y.
96296	Solar Manufacturing Co.	Los Angeles, Calif.
96330	Carlton Screw Co.	Chicago, Ill.
96341	Microwave Associates, Inc.	Burlington, Mass.
96501	Excel Transformer Co.	Oakland, Calif.
97539	Automatic and Precision Mfg. Co.	Yonkers, N.Y.
97966	CBS Electronics, Div. of C.B.S., Inc.	Danvers, Mass.
98141	Axel Brothers Inc.	Jamaica, N.Y.
98220	Francis L. Mosley	Pasadena, Calif.
98278	Microdot, Inc.	So. Pasadena, Calif.
98291	Sealectro Corp.	New Rochelle, N.Y.
98405	Carad Corp.	Redwood City, Calif.
98734	Palo Alto Engineering Co., Inc.	Palo Alto, Calif.
98925	Clevite Transistor Prod. Div. of Clevite Corp.	Waltham, Mass.
98978	International Electronic Research Corp.	Burbank, Calif.
99109	Columbia Technical Corp.	New York, N.Y.
99313	Varian Associates	Palo Alto, Calif.
99515	Marshall Industries, Electron Products Division	Pasadena, Calif.
99800	Delevan Electronics Corp.	East Aurora, N.Y.
99821	North Hills Electric Co.	Great Neck, L.I., N.Y.
99848	Wilco Corporation	Indianapolis, Ind.
99934	Renbrandt, Inc.	Boston, Mass.
99942	Hoffman Semiconductor Div. of Hoffman Electronics, Corp.	Evanston, Ill.
99957	Technology Instruments Corp. of Calif.	No. Hollywood, Calif.

THE FOLLOWING H-P VENDORS HAVE NO NUMBER ASSIGNED IN THE LATEST SUPPLEMENT TO THE FEDERAL SUPPLY CODE FOR MANUFACTURERS HANDBOOK.

0000C	Connor Spring Mfg. Co.	San Francisco, Calif.
0000D	Connex Corp.	Oakland, Calif.
0000E	Fisher Switches, Inc.	San Francisco, Calif.
0000F	Malco Tool and Die	Los Angeles, Calif.
0000G	Microwave Engineering Co.	Palo Alto, Calif.
0000H	Philco Corp. (Lansdale Division)	Lansdale, Pa.
0000I	Telefunken (c/o American Elite)	New York, N.Y.
0000L	Winchester Electronics, Inc.	Santa Monica, Calif.
0000M	Western Coil Div. of Automatic Ind., Inc.	Redwood City, Calif.
0000N	Nahm-Bros. Spring Co.	San Leandro, Calif.
0000P	Ty-Car Mfg. Co., Inc.	Holliston, Mass.
0000R	Metro Cap. Div., Metropolitan Telecommunications Corp.	Brooklyn, N.Y.
0000S	Moulton Electronics	San Carlos, Calif.
0000T	Texas Instruments, Inc. Metals and Controls Div.	Versailles, Ky.

00015-9
Revised: 8 May 1961

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H4-1 Dated Oct. 1960
H4-2 Dated Oct. 1960

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Electro Scientific Industries
7524 S. W. MACADAM AVE. • PORTLAND 19, OREGON

VOLTAGE DIVIDERS

DECEMBER 1962

MODEL
LC-875B

Instruction Manual
VOLTAGE DIVIDER
LEAD
COMPENSATOR

T.O. 33-A1-12-450-1

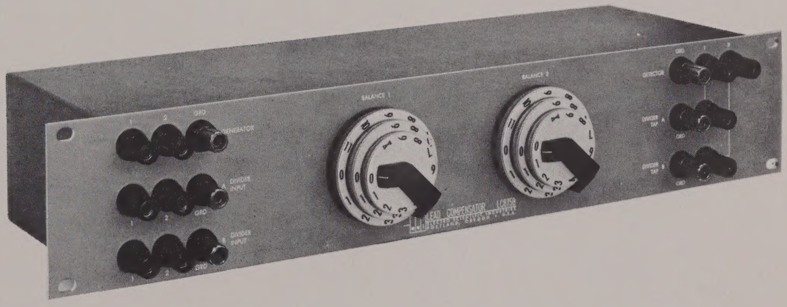

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TABLE OF CONTENTS

I. GENERAL

- 1.1 DESCRIPTION
- 1.2 SPECIFICATIONS

II. OPERATING INSTRUCTIONS

III. THEORY

IV. PREVENTIVE MAINTENANCE

- 4.1 VISUAL INSPECTION
- 4.2 REMOVING THE DUST COVER
- 4.3 CLEANING AND LUBRICATION
- 4.4 REPLACING THE DUST COVER

V. PARTS LIST

SECTION I

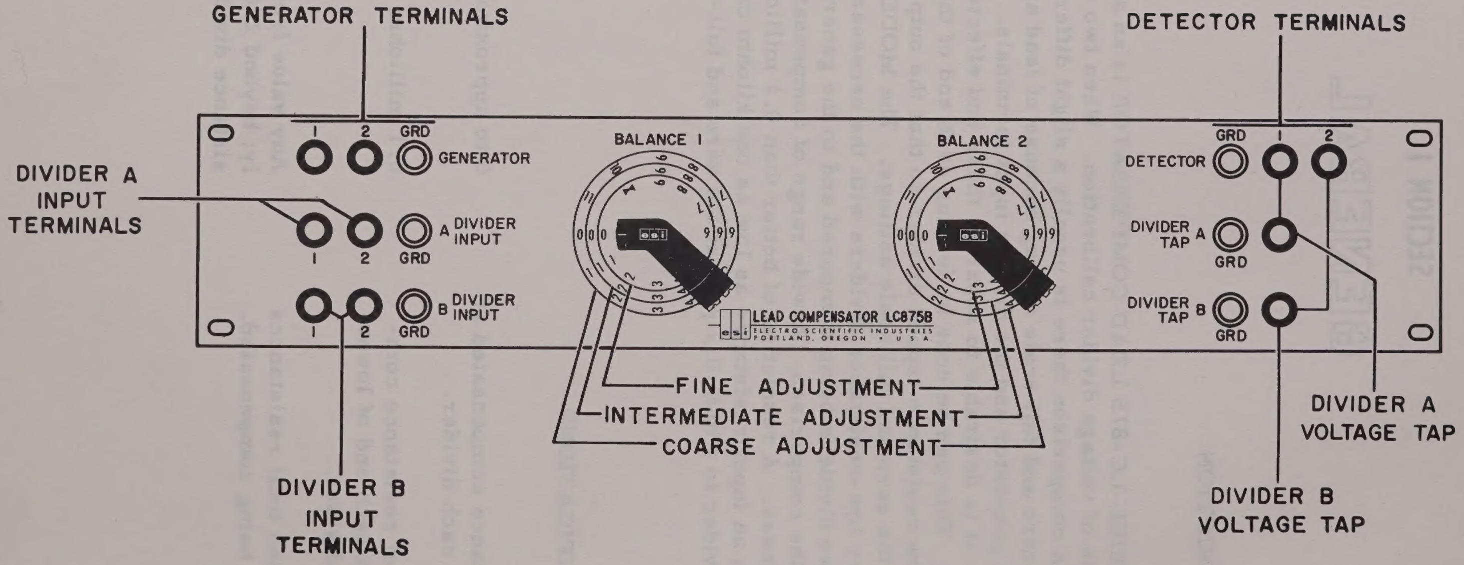
GENERAL

1.1 DESCRIPTION

The ESI MODEL LC-875 LEAD COMPENSATOR is an accessory used to increase the precision of voltage divider calibration. When two dividers are connected for making a comparison there is usually a slight difference between their output voltages at zero and full scale setting because of lead and contact resistances between the generator and the divider input terminals. For precision divider calibration, it is desirable to separate these end effects from the rest of the calibration. This can be done by feeding each end of the divider combination through a low resistance tapped divider so that the output voltages can be made to agree at the zero and full scale settings. The MODEL LC-875 combines these two auxiliary low-resistance dividers with the necessary terminals for connecting to the two dividers being compared and to the generator and null detector necessary for the comparison. A wide range of compensation is provided for maximum usefulness. A resolution of better than 0.1 milliohm is provided so that a divider with an input resistance as low as one kilohm can be set to agree with the standard divider to within 0.1 ppm at the zero and full-scale points.

1.2 SPECIFICATIONS

Lead resistance compensated at each end of each divider.	0 to approximately 150 milliohms
Resolution of resistance compensation at each end of lower resistance divider.	0.1 milliohm
Ratio between total resistances of dividers being compensated.	Any value from 1:1 to 250:1 directly; beyond 250:1 shunt the higher resistance divider with a resistor.

GENERATOR TERMINALS
DETECTOR TERMINALS
DIVIDER A INPUT TERMINALS
1
2
GRD
GENERATOR
A DIVIDER INPUT
B DIVIDER INPUT
BALANCE 1
BALANCE 2
esi
LEAD COMPENSATOR LC875B
ELECTRO SCIENTIFIC INDUSTRIES
PORTLAND, OREGON • U S A
DETECTOR
DIVIDER TAP A
DIVIDER TAP B
FINE ADJUSTMENT
INTERMEDIATE ADJUSTMENT
COARSE ADJUSTMENT
DIVIDER B INPUT TERMINALS
DIVIDER A VOLTAGE TAP
DIVIDER B VOLTAGE TAP

SECTION II

OPERATING INSTRUCTIONS

a) Connect a dc generator* or battery to GEN 1 and 2 terminals, and a sensitive dc detector* to DET 1 and 2 terminals. Connect DET 1 terminal to the GRD terminal if there is no other ground connection in the circuit This grounds the tap of the divider A so that all insulation leakage resistances appear across divider A and not across divider B. The divider with the low input resistance should be connected to the divider A input terminals.

NOTE: The maximum generator voltage should not exceed 1500V peak, and the maximum current should be 2 amperes or less.

b) Connect each of the two voltage dividers to one of the sets of divider terminals with the high (maximum) end to the INPUT 1 terminals, and the low (minimum) end to the INPUT terminal. Connect the divider output to the corresponding DIVIDER TAP terminal at the right. If the dividers have different resistances, connect the lower resistance divider to the A divider terminals. If the detector is sensitive to stray ac pickup, use shielded test leads and connect their shields to GRD terminals. The shielded leads to the divider input terminals must have a very high insulation resistance if high resistance dividers are being compared.

c) With both dividers set at their high (maximum) ends, adjust the BALANCE 1 dials for a detector null indication. The outside dial is for coarse adjustment and the inner dials are for fine balance. Then set both dividers at their low ends and adjust the BALANCE 2 dials for a null in the same manner as above. If a balance appears to be above the maximum balance setting, connect a resistance somewhat less than 250 times the resistance of divider A in parallel with divider B. If the balance appears to be below the minimum balance setting, connect a resistance approximately equal to that of divider B in parallel with divider A.

d) If it is convenient, a relatively high resistance standard divider may be connected permanently to the DIVIDER B terminals.

* NOTE: The GEN and DET terminals match those on any ESI rack-mounted generator-detector placed above the lead compensator panel.

SECTION III

THEORY

Ideally, the only resistances in the circuit in Figure 1 are the resistive voltage dividers R_A and R_B. With the voltage tap on each of the dividers connected to a detector (DET) and set at its high end as shown, there will be a null reading on the detector if these two points are at the same potential. However, there are other resistances and corresponding voltage drops in the circuit for which an account must be made. These resistances, R_X, R_Y, and R_L (Figure 2) are contact and wiring resistances.

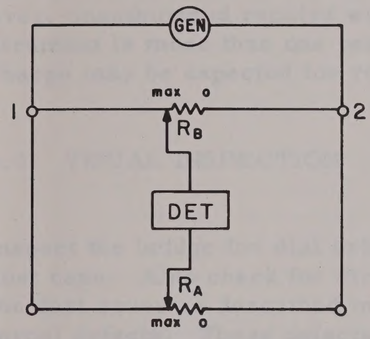


Fig. 1

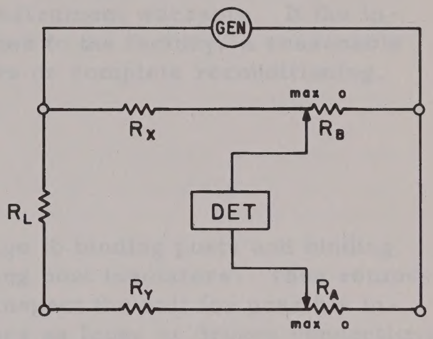


Fig.. 2

Obviously, the detector will not read a null since its contact points are not at the same potential. To correct for this difference, the divider tap potentials must be made to agree. This can be done by connecting each of the dividers R_A and R_B to a low-resistance compensating divider as shown in Figure 3. The LC-875 provides two such low resistance compensating dividers, adjustable, with high resolution over a wide range, as shown in the simplified circuit diagram in Figure 4.

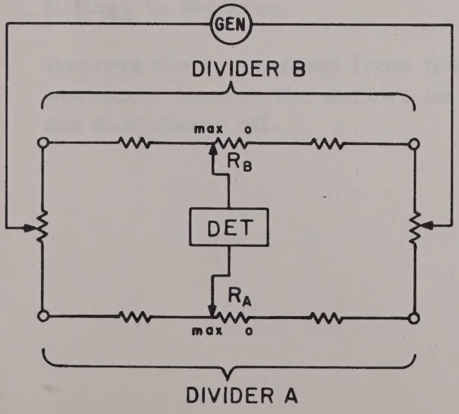


Fig. 3

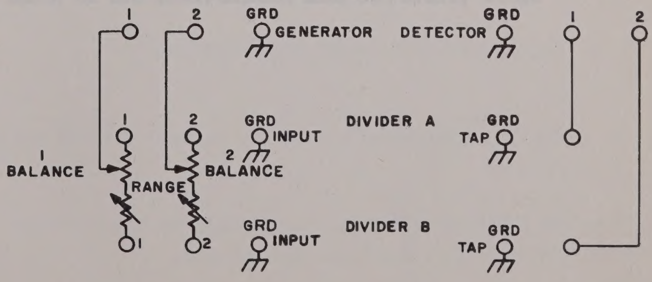


Fig. 4

SECTION IV

PREVENTIVE MAINTENANCE

The following procedures should be performed periodically (approximately once a year) to insure maximum accuracy and reliability from the ESI MODEL LC-875B LEAD COMPENSATOR.

If the need for major repairs is apparent, it is recommended that the unit be sent to the factory for service. The service department will be glad to furnish the necessary information for repairs as well as any replacement parts. However, unauthorized repairs will invalidate the instrument warranty. If the instrument is more than one year old when returned to the factory, a reasonable charge may be expected for replacement of parts or complete reconditioning.

4.1 VISUAL INSPECTION

Inspect the bridge for dial orientation and damage to binding posts and binding post caps. Also check for dirt around the binding post insulators. Then remove the dust cover as described in Section 4.2 and inspect the unit for possible internal defects. These defects include such things as loose or broken connections, damaged or dirty switch contacts, worn or dirty potentiometers and sliders, and heat damaged resistors.

4.2 REMOVING THE DUST COVER

Prepare a soft, clean place to set the instrument. Be sure that no projections or pointed objects will be underneath the panel. See that there are no metal fillings in the area.

Remove the instrument from the rack and place it face down on the prepared surface. Loosen the screws on the back of the instrument and carefully slide the dust cover off.

4.3 CLEANING AND LUBRICATION

Clean the front panel with a soft, dry, lint-free cloth, being particularly careful to remove all dirt from around the binding post insulators. The only internal components which require cleaning and lubrication are the potentiometers, and occasionally the switch decks. Clean and lubricate the potentiometers as follows:

> CAUTION: Do not use solvents on the potentiometers. Solvents will leave a residue which may affect their performance.

a) Polish the contact surfaces lightly with an abrasive cloth (Crocus cloth or equivalent).

b) Remove loose particles by wiping with a nylon cloth.

c) Apply a moderate amount of pure petroleum jelly to the contact surfaces.

The switch decks are carefully lubricated at the time of manufacture and are protected from contamination by the dust cover. They should rarely, if ever, require maintenance. It is recommended that they be cleaned or lubricated only if it is determined that they are not making good electrical contact. If the switch decks are in need of cleaning or lubrication, proceed as follows:

a) Apply solvent (Freon printed circuit solvent or equivalent) to the contact surfaces with a small brush or pipe cleaner.

b) Wipe surfaces with clean, dry brush or dry with low pressure air.

c) Apply a thin coating of lubricant (Oak #2008 or equivalent) to the contact surfaces with a hypodermic needle.

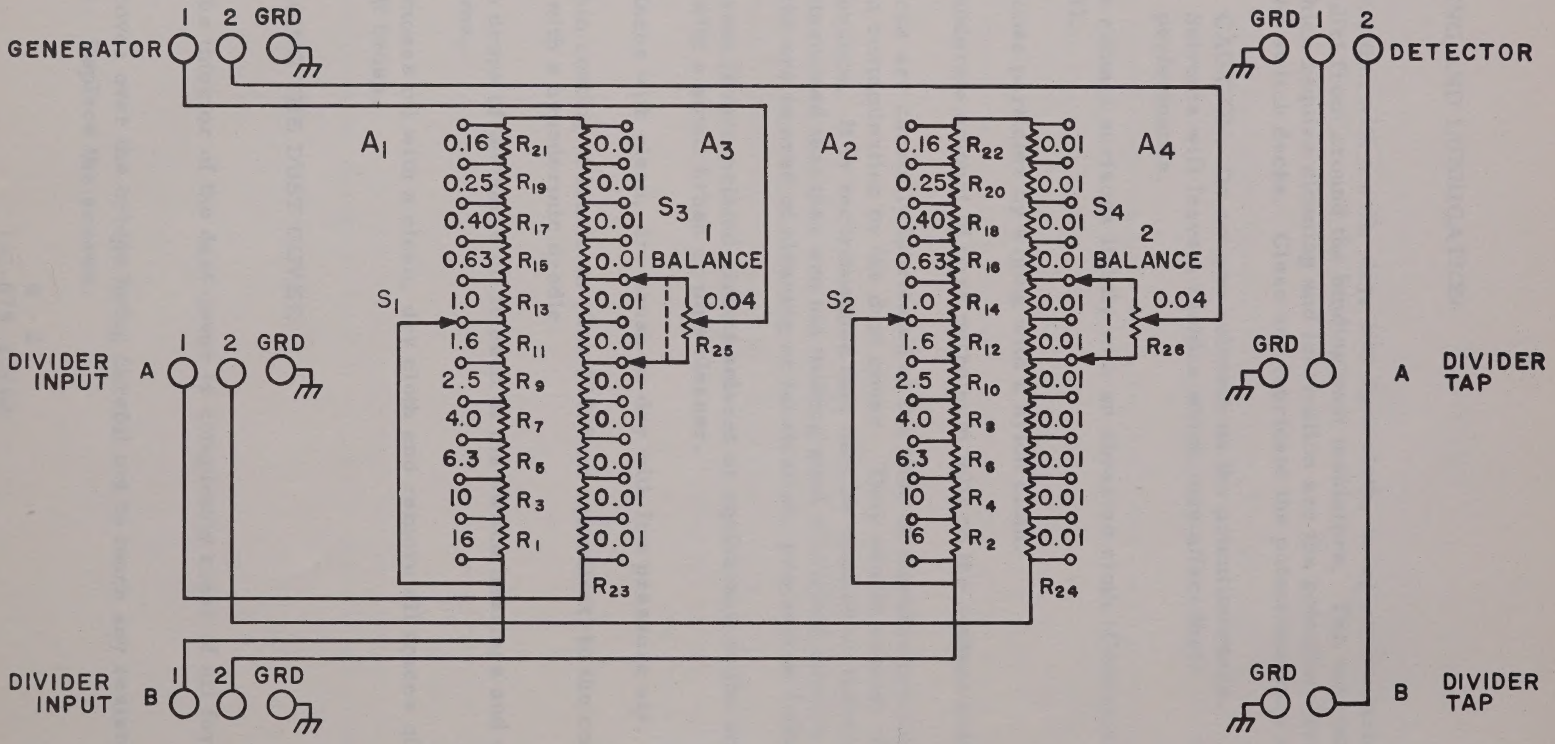
d) Apply two drops of the same oil to each of the switch bearings and detent mechanisms.

e) Remove excess oil with a clean, dry cloth and remove all traces of lint with a soft brush.

4.4 REPLACING THE DUST COVER

Be sure that the interior of the dust cover is completely clear of all foreign material.

Slip the dust cover over the bridge being careful not to touch any resistors with the cover. Replace the screws.



LC-875 CIRCUIT DIAGRAM

PARTS LIST

The following parts list is in alpha numerical order of the circuit reference designator. Miscellaneous parts are included at the end of the list. Manufacturer of the part is given in a code number according to the Federal Supply Code for Manufacturers; see list of manufacturers below. Parts recommended as spares to sustain operation in isolated locations are indicated in the recommended spare parts column.

Parts manufactured by Electro Scientific Industries must be ordered from the factory. When ordering parts from the factory include the following information:

- Model and serial number of the instrument
- Electro Scientific Industries part number
- Circuit reference designator
- Description of part

CODE LIST OF MANUFACTURERS

11837	ELECTRO SCIENTIFIC INDUSTRIES Portland, Oregon

Ckt Ref	Description	Mfr.	ESI Part No.	Qty Used	Recm SP
$A_{1,2}$	Ass'y, Sw, Res	11837	9030	2	
$A_{3,4}$	Ass'y, Sw, Res	11837	9024	2	
$R_{1,2}$	Res, Fxd, WW, 16Ω Part of Ass'y $A_{1,2}$	11837	*	2	
$R_{3,4}$	Res, Fxd, WW, 10Ω Part of Ass'y $A_{1,2}$	11837	*	2	
$R_{5,6}$	Res, Fxd, WW, 6.3Ω Part of Ass'y $A_{1,2}$	11837	*	2	
$R_{7,8}$	Res, Fxd, WW, 4.0Ω Part of Ass'y $A_{1,2}$	11837	*	2	
$R_{9,10}$	Res, Fxd, WW, 2.5Ω Part of Ass'y $A_{1,2}$	11837	*	2	

* Replace entire Ass'y

Ckt Ref	Description	Mfr.	ESI Part No.	Qty Used	Recm SP
$R_{11,12}$	Res, Fxd, WW, 1.6Ω Part of Ass'y $A_{1,2}$	11837	*	2	
$R_{13,14}$	Res, Fxd, WW, 1.0Ω Part of Ass'y $A_{1,2}$	11837	*	2	
$R_{15,16}$	Res, Fxd, WW, 0.63Ω Part of Ass'y $A_{1,2}$	11837	*	2	
$R_{17,18}$	Res, Fxd, WW, 0.40Ω Part of Ass'y $A_{1,2}$	11837	*	2	
$R_{19,20}$	Res, Fxd, WW, 0.25Ω Part of Ass'y $A_{1,2}$	11837	*	2	
$R_{21,22}$	Res, Fxd, WW, 0.16Ω Part of Ass'y $A_{1,2}$	11837	*	2	
$R_{23,24}$	Res, Tapped, 0.01Ω per step, Part of Ass'y $A_{3,4}$	11837	*	2	
$R_{25,26}$	Res, Var, 0.04Ω	11837	9025	2	
$S_{1,2}$	Sw, Rot, Part of Ass'y $A_{1,2}$	11837	*	2	
$S_{3,4}$	Sw, Rot, Part of Ass'y $A_{3,4}$	11837	*	2	
	MISCELLANEOUS				
	Dial, 1st	11837	4769	2	
	Dial, 2nd	11837	4912	2	
	Dial, Pot	11837	4772	2	
	Bushing, Split	11837	6822	2	2
	Binding Post	11837	1393	16	

* Replace entire ass'y

Parts List
ESI MODEL LC-875B

Ckt Ref	Description	Mfr.	ESI Part No.	Qty Used	Recm SP
	Cap, Binding Post, Ins.	11837	1294	10	4
	Cap, Binding Post, Metal	11837	1296	6	3
	Indicator, Dial	11837	4864	2	1
	Bracket, Indicator	11837	4966	2	
	Insulator, Binding Post, Shoulder	11837	8823	10	
	Cover, Dust	11837	7905	1	

Electro/Scientific Industries
13900 N. W. SCIENCE PARK DRIVE • PORTLAND, OREGON 97229

VOLTAGE DIVIDERS

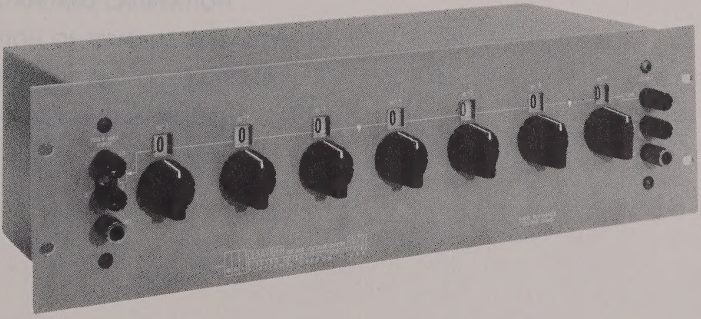
MARCH 1964

MODEL

RV722

Instruction Manual

KELVIN VARLEY RESISTIVE VOLTAGE DIVIDER



SERIAL NUMBER __________

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TABLE OF CONTENTS

I INTRODUCTION

1.1 DESCRIPTION

1.2 SPECIFICATIONS

II AIDS TO OPERATION

2.1 POWER LIMITATIONS

2.2 TEMPERATURE AND POWER EFFECTS

2.3 LOADING EFFECTS

2.4 USING CERTIFICATE CORRECTIONS

III CALIBRATION

3.1 EQUIPMENT REQUIRED

3.2 TRANSFER STANDARD CALIBRATION

3.3 DETERMINATION OF TERMINAL LINEARITY

3.4 DETERMINATION OF END CORRECTIONS

3.5 CECKING THE POWER COEFFICIENT

IV PARTS LIST

V APPENDIX

SECTION I

INTRODUCTION

1.1 DESCRIPTION

The Model RV 722 DEKAVIDER® Decade Voltage Divider is a laboratory-standard resistive divider. It uses a Kelvin-Varley circuit for high accuracy, repeatability, and stability. The circuit schematic is illustrated in Figure 1.1A.

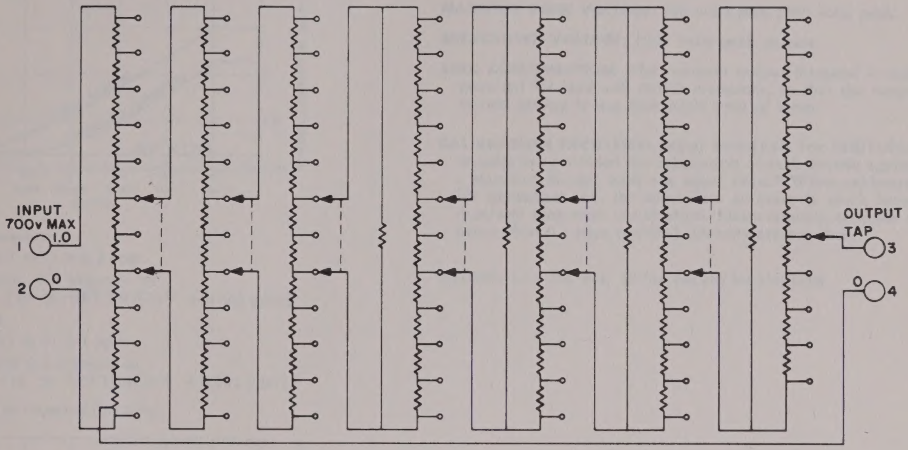


Figure 1.1A

Decade dials indicate the output voltage in proportional parts of the input. The output can be read to seven significant digits. The compensated voltage at the output common (terminal 4) is factory adjusted to equal the voltage at the output tap (terminal 3) when the divider is set to 000,000,0. This provides high accuracy for low-output voltage applications.

The equivalent circuit of the Model RV 722 is shown in Figure 1.1B. The Kelvin-Varley equivalent circuit looks like a simple potentiometer or tapped resistor, except that it has additional resistance in series with the tap.

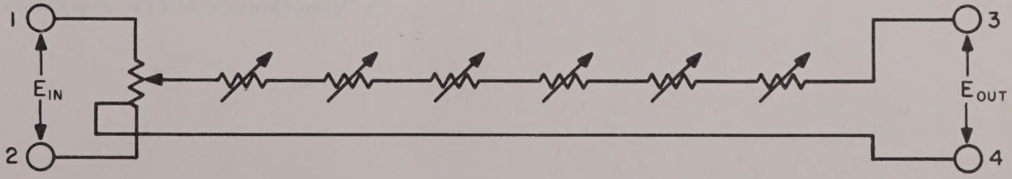


Figure 1.1B

The Model RV 722 may be mounted in any standard 19 inch rack. Electrostatic shielding is provided by the metal panel and dust cover which are isolated from the active circuit. High accuracy and resolution of the divider make it ideally suited for many applications. Dividers, potentiometers and ratio sets can be calibrated accurately. Voltage and current measuring devices can be checked easily. The precision ratio available can be used for high accuracy impedance comparisons. The RV 722 is suited for use at low frequency ac as well as dc.

1.2 SPECIFICATIONS

CIRCUIT: Kelvin-Varley Resistive Divider.

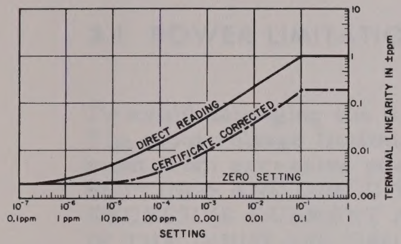
NUMBER OF DECADES: Seven.

RESOLUTION: 10,000,000 Divisions—0.1 ppm steps.

INPUT RESISTANCE: 100 Kilohms ±0.005%.

TERMINAL LINEARITY:

At time of final inspection:



Certificate Corrected

Settings of 0.1 to 1: ±0.2 ppm.

Settings below 0.1 improve to

$\pm\{0.2 \text{ ppm } (10 \times \text{SETTING})^{2/3} + 0.002 \text{ ppm}\}$.

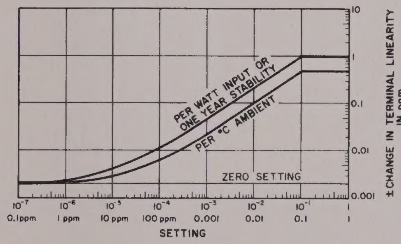
Direct Reading

Settings of 0.1 to 1: ±1 ppm.

Settings below 0.1 improve to

$\pm \{1 \text{ ppm } (10 \times \text{SETTING})^{2/3} + 0.002 \text{ ppm}\}$.

Limit of changes in terminal linearity:



Stability

Settings of 0.1 to 1: ±1 ppm. / yr.

Settings below 0.1 improve to

$\pm \{1 \text{ ppm } (10 \times \text{SETTING})^{2/3} + 0.002 \text{ ppm}\} / \text{yr}$.

Temperature Coefficient (20°C to 30°C)

Settings of 0.1 to 1: ±0.5 ppm/° C.

Settings below 0.1 improve to

$\pm \{0.5 \text{ ppm } (10 \times \text{SETTING})^{2/3} + 0.002 \text{ ppm}\} / ° \text{C}$

Power Coefficient

Settings of 0.1 to 1: ±1 ppm/watt.

Settings below 0.1 improve to

$\pm \{1 \text{ ppm } (10 \times \text{SETTING})^{2/3} + 0.002 \text{ ppm}\} / \text{watt}$

SWITCHES: Solid silver alloy rotor and stator contacts. Four independent electrically parallel wiping surfaces per switch contact.

Silicone treated ceramic insulation.

MAXIMUM INPUT POWER: Five watts (700 volts d c or rms).

MAXIMUM INPUT VOLTAGE: 700 volts rms, 1000 volts peak.

BREAKDOWN VOLTAGE: 1000 volts peak to case.

ZERO COMPENSATION: The common output terminal is compensated for lead and switch resistance, so that the output at zero setting is less than 0.004 ppm of input.

CALIBRATION FACILITIES: Input terminals for individual decades are provided for calibration of each decade against a standard divider with ten equal steps.* When calibrated for immediate use, the short-term accuracy is much better than any long-term certification. Measurements accurate to better than 0.2 ppm terminal linearity are possible.

WEIGHT: 12.5 lbs net, 18 lbs packed for shipping.

SECTION II

AIDS TO OPERATION

The Kelvin-Varley divider is designed primarily for use in null-balance circuits or as a voltage source for high impedance circuits. It cannot be used as a simple variable resistor because of the additional resistance in series with the tap (see Figure 1.1B). The resistance ratios between the taps of a Kelvin-Varley divider are not linearly related to the voltage ratios.

2.1 POWER LIMITATIONS

To avoid damaging the RV 722, it is necessary to take certain precautions. The input voltage limitation of 700 volts will normally protect the instrument from excessive power dissipation. However, WITH CERTAIN DIAL SETTINGS AND CIRCUIT CONNECTIONS IT IS POSSIBLE TO DRAW EXCESSIVE CURRENT AND PERMANENTLY DAMAGE THE INSTRUMENT IF THE INPUT VOLTAGE IS MAINTAINED. FOR THIS REASON THE SOURCE SHOULD BE POWER-LIMITED TO ONE WATT IF POSSIBLE. This can be done by inserting a resistor with a value $R = \frac{E^2}{4}$ in series with the supply voltage E. Another method of protecting the divider is to fuse the output with a 10 ma fuse.

2.2 TEMPERATURE AND POWER EFFECTS

Figure 2.2A illustrates the division of current and power in the RV 722 resistors. The temperature rise in each resistor is almost directly proportional to the power applied to it.

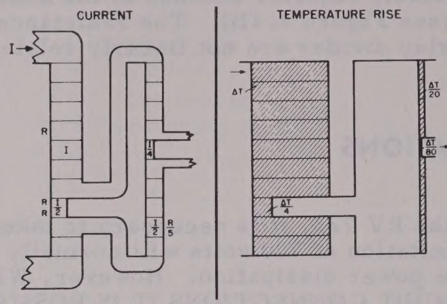


Figure 2.2A

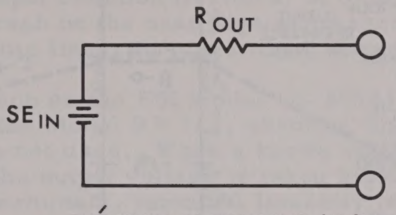
Uneven power distribution results from the shunting of two of the eleven resistors in each decade by the next decade (refer to Figure 1.1A). As a result of this uneven power distribution, the shunted resistors do not get as hot as the rest. Therefore, if the divider is to be run at fairly high power and the first decade is switched, a short time should be allowed for the redistribution of heat in the resistors.

2.3 LOADING EFFECTS

When a load is placed across the output of the RV 722, the output voltage will change. This change in output voltage may or may not have to be considered in the measurement being made, depending on the degree of accuracy desired. With high impedance loads the effect of the load may be less than the effect of the linearity deviation. In this case the change in output voltage due to output loading can be neglected.

The RV 722 can be represented by an equivalent generator and output resistor in series, as shown in Figure 2.3A. With this equivalent circuit and a known load resistance, the effect on output voltage can be easily analyzed. Variations in output voltage can be expressed as LINEARITY DEVIATION (deviation from nominal output in proportional parts of the input), or as OUTPUT DEVIATION (the deviation from nominal output in proportional parts of the output).

Figure 2.3A



THÉVENIN EQUIVALENT CIRCUIT

Figure 2.3B is a plot of the output resistance of the RV 722 as a function of its dial setting. The resistance values are symmetrical about a setting of .500,000,0. For example, the output resistance at a setting of .985,000,0 will be the same as that for a setting of .015,000.0. The resistance corresponding to .255,555,5 can be easily found in Figure 2.3B. With the Kelvin-Varley circuit the maximum output resistance occurs at settings of .455,555,5 and .544,444,4. The output resistance measurements are made by shorting the input terminals together and measuring the resistance across the output terminals.

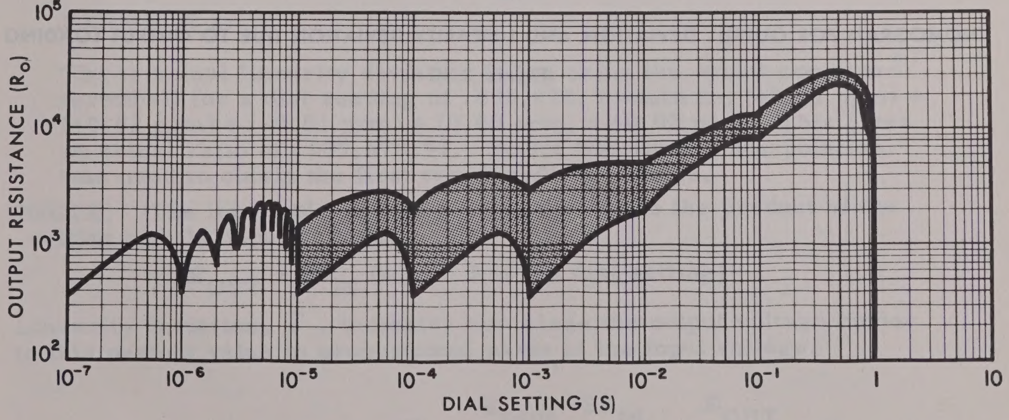
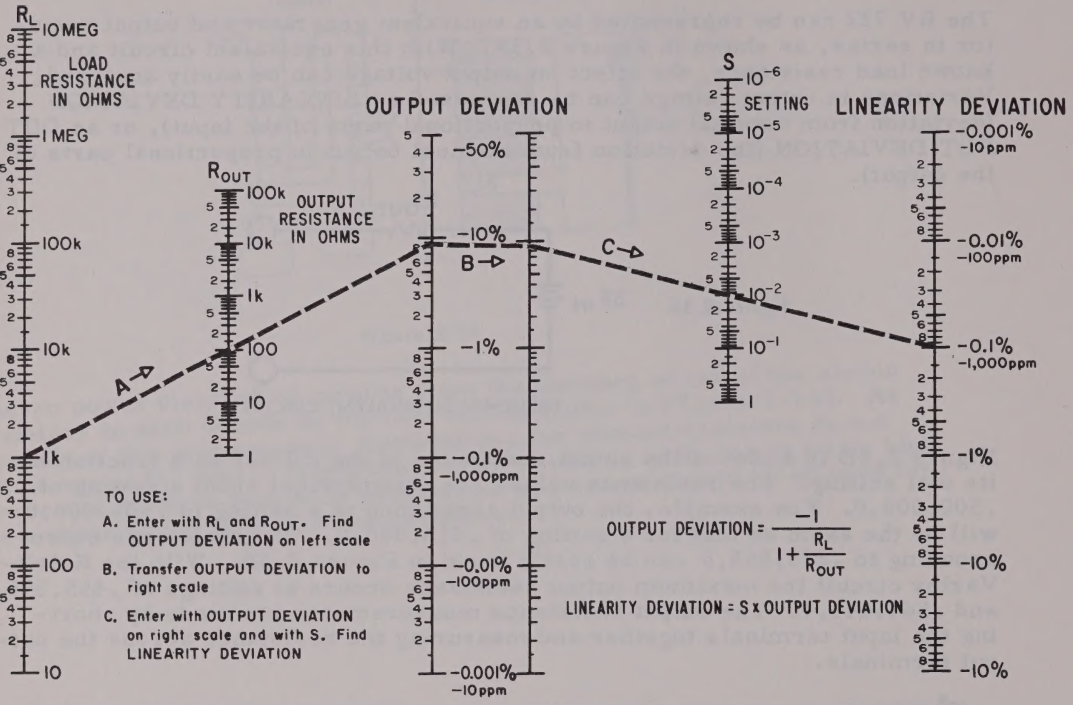


Figure 2.3B

The nomogram in Figure 2.3C is for determining the linearity deviation and output deviation when the load resistance, output resistance and dial setting are known.



TO USE:

A. Enter with R_L and R_{OUT}. Find OUTPUT DEVIATION on left scale

B. Transfer OUTPUT DEVIATION to right scale

C. Enter with OUTPUT DEVIATION on right scale and with S. Find LINEARITY DEVIATION

$$\text{OUTPUT DEVIATION} = \frac{-1}{1+\frac{R_L}{R_{OUT}}}$$

LINEARITY DEVIATION = S x OUTPUT DEVIATION

NOMOGRAM FOR OUTPUT DEVIATION AND LINEARITY DEVIATION DUE TO OUTPUT LOADING

Figure 2.3C

2.4 USING CERTIFICATE CORRECTIONS

Each RV 722 is factory calibrated before shipment. The calibration certificate accompanies the instrument and can be used to increase measurement accuracy. The certificate includes four separate correction graphs. These graphs may be used to determine the amount of linearity deviation* at any dial setting.

Sample calibration certificate graphs on the next page illustrate the linearity deviation which might be contributed by the first decade, the second decade, the third decade and by internal lead and contact resistances.

The divider accuracy relative to the minimum and maximum voltages available at the output tap (terminal 3) is called absolute linearity. Terminal linearity is the accuracy relative to the voltage between the input (terminal 1) and either the input common (terminal 2) or the output common (terminal 4). The bottom graph on the next page expresses the correction needed to change from absolute linearity to terminal linearity.

When a lead compensator (such as the ESI Model LC 875A) is used to compare another divider to the Model RV 722, absolute linearity is generally used and the bottom graph is not used. When a known voltage is connected to the input terminals, and the output voltage is taken between the output tap and one of the common terminals, terminal linearity is used.

Notice that the bottom graph has two lines plotted on it. The line extending from zero deviation is the plot used when the output voltage is measured between the output tap and the output common. The other line is used when the output voltage is measured between the output tap and the input common.

EXAMPLE 1:

The absolute linearity deviation for a dial reading of .678,912,3 would be; (-0.13 ppm) + (+0.05 ppm) + (0.00 ppm) = -0.08 ppm. This gives an actual ratio of 0.678,912,22.

EXAMPLE 2:

The terminal linearity deviation (when using the output common terminal) for a dial reading of .005,678,9 would be; (+0.01 ppm) + (+0.02 ppm) + (-0.01 ppm) + (0.00 ppm) = +0.02 ppm. This gives an actual ratio of .005,678,92. Notice that linear interpolation was used to obtain the first two decade deviations.

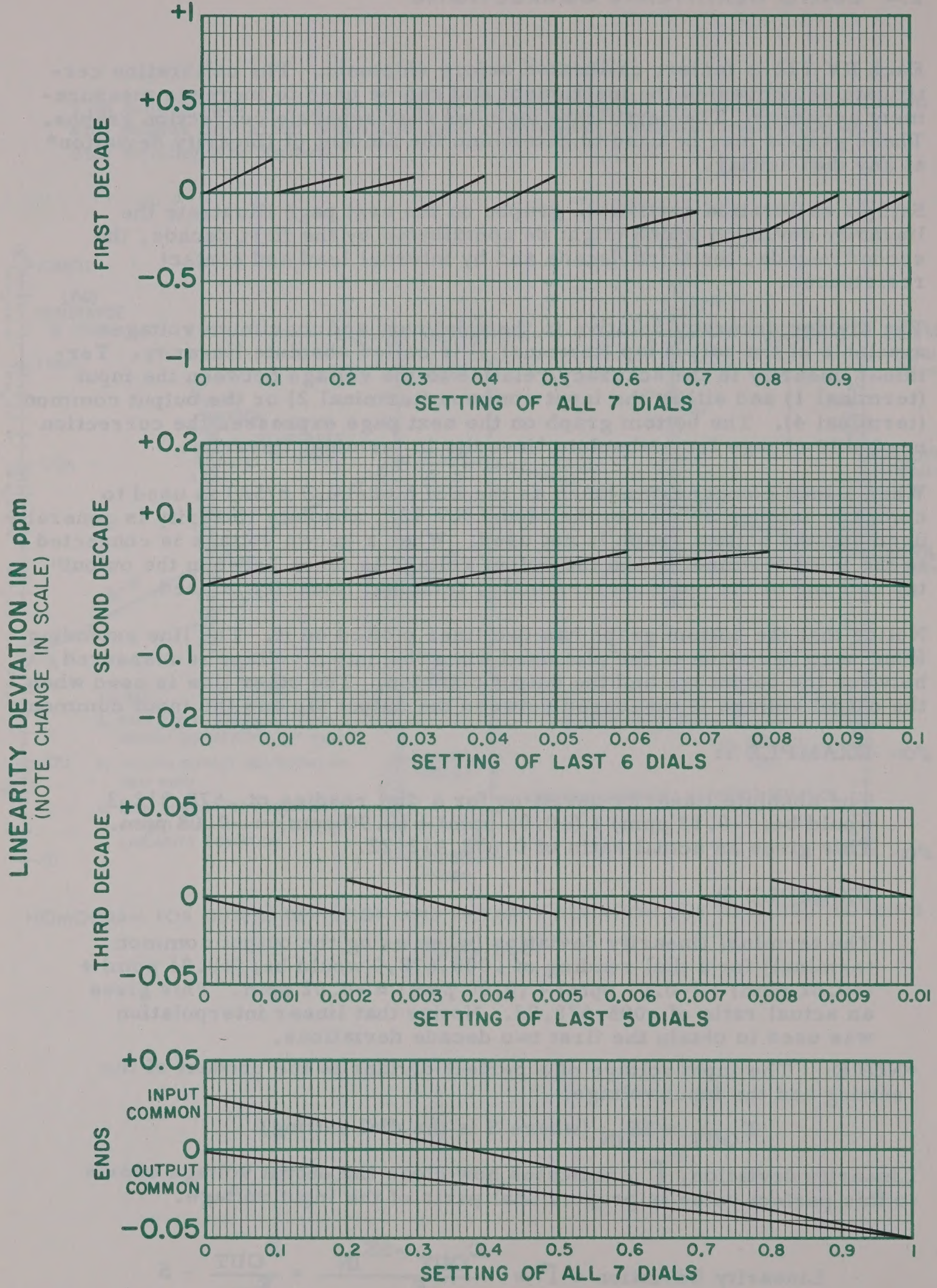
*NOTE: The input voltage of a perfect divider is the product of the setting and the input voltage;

$$E_{OUT} = SE_{IN} \text{ (where S is the dial setting)}$$

Linearity deviation, Γ, indicates how close the output voltage comes to this perfect value in proportional parts of the input voltage.

$$\text{Linearity Deviation} = \Gamma = \frac{E_{OUT} - SE_{IN}}{E_{IN}} = \frac{E_{OUT}}{E_{IN}} - S ,$$

MODEL RV 722 KELVIN - VARLEY VOLTAGE DIVIDER



23 °C
TEMPERATURE

SECTION III

CALIBRATION

The RV 722 is a highly stable and accurate divider, however, to use its short-term stability to the fullest advantage it should be recalibrated shortly before being used. The conditions under which the divider is calibrated should duplicate the ambient temperature and excitation voltage as closely as is practical. This will minimize the effect of temperature differences and slow drifts in the divider.

3.1 EQUIPMENT REQUIRED

1) A ten-step, 100k input total, resistive divider with provisions for intercomparing the individual resistors (ESI Model SR 1010 Resistance Transfer Standard, 10k per step).

2) A dc source capable of delivering 300 volts to a 100k load, power-limited to one watt (ESI Model 800 DC Generator-Detector).

3) A high impedance (1 megohm or greater) microvolt meter with a 100 microvolt full scale range and capable of resolving one-half microvolt or less (ESI Model 800 DC Generator-Detector).

4) Low resistance lead-compensating potentiometers (ESI Model LC 875B Lead-Compensator).

The dc source and lead-compensating potentiometers should be isolated from ground by at least 10^{11} ohms.

3.2 TRANSFER STANDARD CALIBRATION

Intercompare the resistors of the transfer standard and calculate the linearity deviation (Γ) by the formula;

$$\Gamma = \frac{1}{10} \sum_{n=1}^{10S} (\Delta_n - \Delta_{AV})$$

where Δ_n is the measured deviation of the n^{th} resistor and Δ_{AV} is the average deviation of the ten resistors.

Figure 3.2A illustrates an example of such a calculation.

RESISTOR NUMBER	MEASURED DEVIATION PPM	DIFFERENCE FROM THE AVERAGE PPM	LINEARITY DEVIATION Γ PPM
10S	Δ_n	$\Delta_n - \Delta_{AV}$	$\frac{1}{10} \sum_{n=1}^{10S} (\Delta_n - \Delta_{AV})$
1	1.4	+0.36	+0.04
2	+0.8	−0.24	+0.01
3	+5.0	+3.96	+0.41
4	+2.2	+1.16	+0.52
5	+2.4	+1.36	+0.66
6	−0.4	−1.44	+0.52
7	+0.4	−0.64	+0.45
8	−2.4	−3.44	+0.11
9	+1.4	+0.36	+0.14
10	−0.4	−1.44	0
TOTAL	$\sum_{n=1}^{10} \Delta_n = +10.4$	0	

LINEARITY CALCULATED FROM RESISTANCE MEASUREMENTS OF AN ESI MODEL SR 1010 DECADE RESISTANCE STANDARD

Figure 3.2A

3.3 DETERMINATION OF TERMINAL LINEARITY

The process for determining the terminal linearity of the divider is as follows:

1) Connect the equipment as shown in Figure 3.3A to determine the linearity deviation of the first decade of the RV 722.

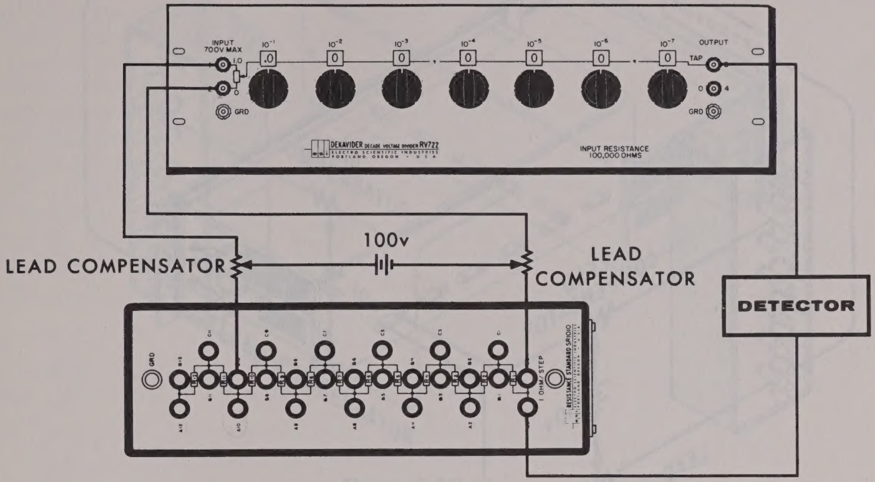


Figure 3.3A

2) Adjust the input voltage to 100 volts for first decade - 10 volts for other decades.

3) With both dividers set at zero (as shown) adjust the lead compensator so the outputs are within 0.1 ppm of each other (100 microvolts = 1 ppm for first decade - 10 microvolts = 1 ppm for other decades).

4) With both dividers set at full scale, adjust the lead compensator so that the outputs are within 0.1 ppm of each other.

5) Measure the linearity difference between the two dividers at nominally equal settings. Two microvoltmeter readings are taken at each setting (with the exception of the last decade), one with all the decades to the right of the first decade set to zero and one with all the decades to the right of the first decade set to their maximum setting. Be sure that the microvoltmeter reads a positive difference when the RV 722 ratio is greater than the ratio of the transfer standard.

6) Correct the transfer standard readings by subtracting the linearity deviation of the transfer standard from these readings. Divide the readings by the appropriate power of ten (divide the second decade readings by ten, the third decade readings by 100, etc.) to convert them to linearity deviation contributions expressed as a fraction of full-scale for the whole divider.

7) Plot the measured deviations as shown in Section 2.4.

8) Connect the equipment as shown in Figure 3.3B.

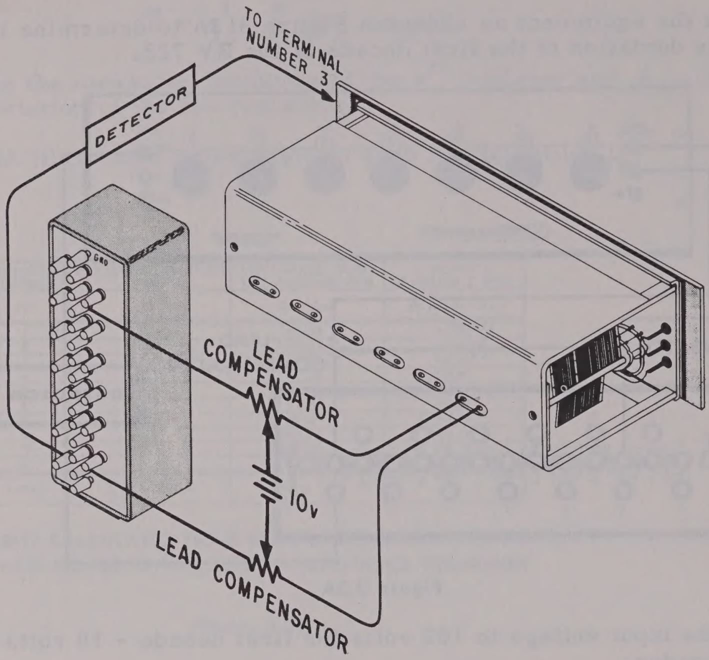


Figure 3.3B

9) Repeat steps 2 through 7 except in step 5 where the two microvoltmeter readings are taken at each setting, one with all the decades to the right of the second decade set to zero and one with all the decades to the right of the second decade set to their maximum settings.

10) Connect the equipment as shown in Figure 3.3C.

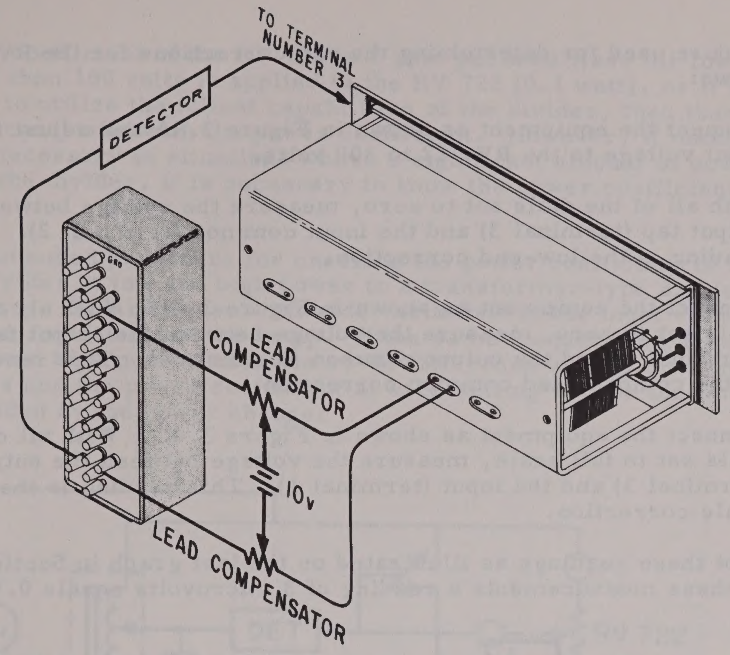


Figure 3.3C

11) Repeat steps 2 through 7 except in step 5 where the two microvoltmeter readings are taken at each setting, one with all the decades to the right of the third decade set to zero and one with all the decades to the right of the third decade set to their maximum settings.

12) The remaining decades may be calibrated in a similar manner, if desired. However, normally, this data is not used.

3.4 DETERMINATION OF END CORRECTION

The procedure used for determining the end corrections for the RV 722 is as follows:

1) Connect the equipment as shown in Figure 3.4A and adjust the input voltage to the RV 722 to 300 volts.

2) With all of the dials set to zero, measure the voltage between the output tap (terminal 3) and the input common (terminal 2). This reading is the low-end correction.

3) Connect the equipment as shown in Figure 3.4B. With all of the dials set to zero, measure the voltage between the output tap (terminal 3) and the output common (terminal 4). This reading is the compensated common correction.

4) Connect the equipment as shown in Figure 3.4C. With all of the dials set to full scale, measure the voltage between the output tap (terminal 3) and the input (terminal 1). This reading is the full-scale correction.

5) Plot these readings as illustrated on the last graph in Section 2.4. In these measurements a reading of 3 microvolts equals 0.01 ppm.

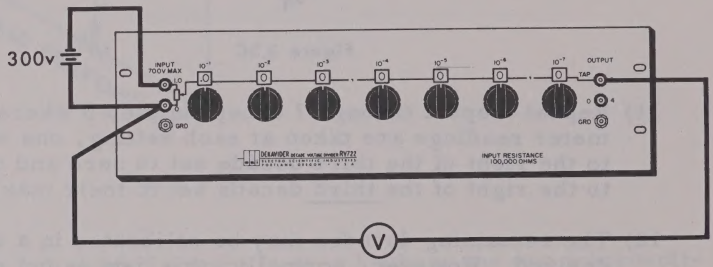

300v
INPUT 700V MAX
1.0
0
GRD
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
.0
0
0
0
0
0
0
OUTPUT
TAP
0
4
GRD
DEKAVIDER DECADE VOLTAGE DIVIDER RV722
ELECTRO SCIENTIFIC INDUSTRIES PORTLAND OREGON · U S A
INPUT RESISTANCE 100,000 OHMS
V

Figure 3.4A

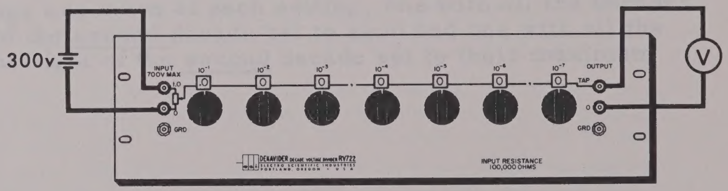

300v
INPUT 700V MAX
1.0
0
GRD
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
.0
0
0
0
0
0
0
OUTPUT
TAP
0
4
GRD
DEKAVIDER DECADE VOLTAGE DIVIDER RV722
ELECTRO SCIENTIFIC INDUSTRIES PORTLAND OREGON · U S A
INPUT RESISTANCE 100,000 OHMS
V

Figure 3.4B

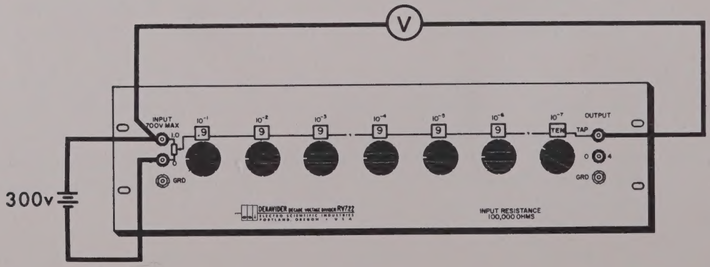

V
INPUT 700V MAX
1.0
0
GRD
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
9
9
9
9
9
9
TEN
OUTPUT
TAP
0
4
GRD
DEKAVIDER DECADE VOLTAGE DIVIDER RV722
ELECTRO SCIENTIFIC INDUSTRIES PORTLAND OREGON · U S A
INPUT RESISTANCE 100,000 OHMS
300v

Figure 3.4C

3.5 CHECKING THE POWER COEFFICIENT

The power coefficient of the RV 722 is 1 ppm per watt (less for low settings). If no more than 100 volts is applied to the RV 722 (0.1 watt), or if it is not necessary to utilize the fullest capabilities of the divider, then there is no need to be concerned with the power coefficient. However, if maximum accuracy is necessary in situations where a significant amount of power is applied to the divider, it is necessary to know the power coefficient of the unit.

The recommended procedure for checking the power coefficient is to compare the divider at low and high power to a transformer-type divider which will not change linearity even with wide variations in the input voltage. See Figure 3.5A for details of the setup. If the same frequency is used at both low power and high power, then the ac-dc difference will be the same at both powers and the power coefficient at each setting will be the linearity change divided by the power change.

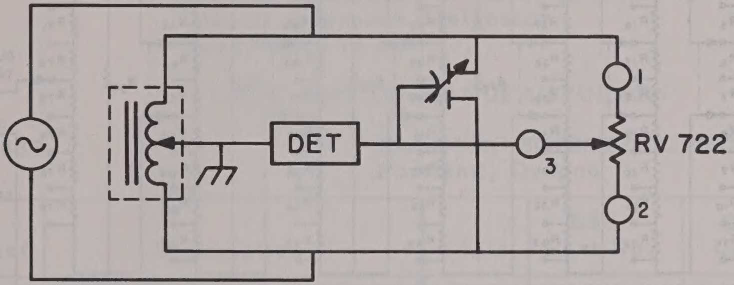
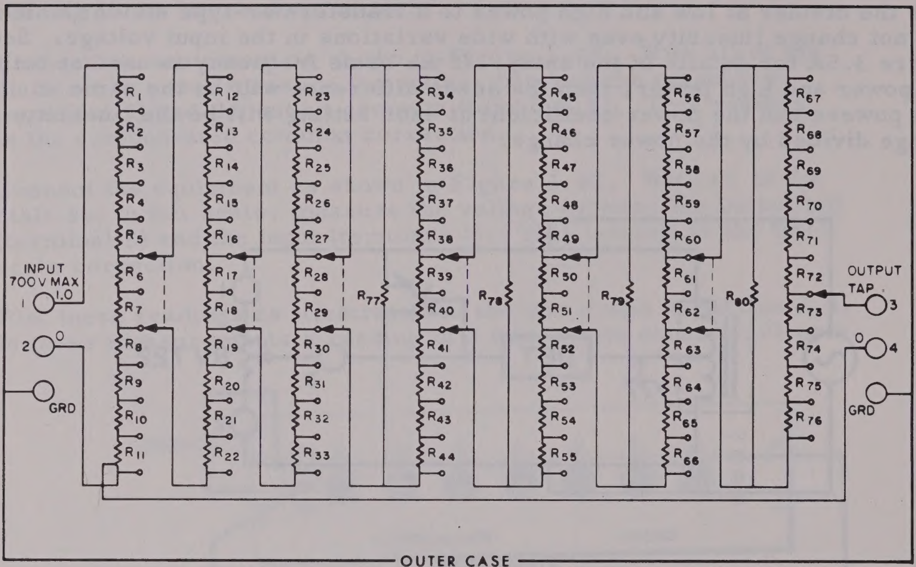
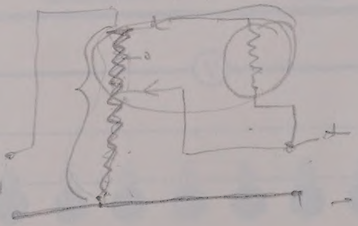


Figure 3.5A


INPUT
700 V MAX
1
1.0
2
0
GRD
R_1 R_2 R_3 R_4 R_5 R_6 R_7 R_8 R_9 R_{10} R_{11}
R_{12} R_{13} R_{14} R_{15} R_{16} R_{17} R_{18} R_{19} R_{20} R_{21} R_{22}
R_{23} R_{24} R_{25} R_{26} R_{27} R_{28} R_{29} R_{30} R_{31} R_{32} R_{33}
R_{77}
R_{34} R_{35} R_{36} R_{37} R_{38} R_{39} R_{40} R_{41} R_{42} R_{43} R_{44}
R_{78}
R_{45} R_{46} R_{47} R_{48} R_{49} R_{50} R_{51} R_{52} R_{53} R_{54} R_{55}
R_{79}
R_{56} R_{57} R_{58} R_{59} R_{60} R_{61} R_{62} R_{63} R_{64} R_{65} R_{66}
R_{80}
R_{67} R_{68} R_{69} R_{70} R_{71} R_{72} R_{73} R_{74} R_{75} R_{76}
OUTPUT
TAP
3
0
4
GRD
OUTER CASE

R_1 thru R_{11}	R_{12} thru R_{22}	R_{23} thru R_{33}	R_{77}	R_{34} thru R_{44}	R_{78}	R_{45} thru R_{55}	R_{79}	R_{56} thru R_{66}	R_{80}	R_{67} thru R_{76}
10k	2k	400Ω	1k	400Ω	1k	400Ω	1k	400Ω	1k	400Ω



SECTION IV

PARTS LIST

The following parts list is in alpha-numerical order of the circuit reference designator. Miscellaneous parts are included at the end of the list. Manufacturer of the part is given in a code number according to the Federal Supply Code for Manufacturers; see list of manufacturers below. Parts recommended as spare parts to sustain operation in isolated locations are indicated in the recommended spare parts column.

Parts manufactured by Electro Scientific Industries must be ordered from the factory. When ordering parts from the factory, include the following information:

Model and serial number of the instrument
Electro Scientific Industries part number
Circuit reference designator
Description of part

CODE LIST OF MANUFACTURERS

11837	ELECTRO SCIENTIFIC INDUSTRIES Portland, Oregon

Ckt Ref	Description	Mfr	ESI Part No.	Qty Used	Recm SP
A_1	Switch Assy, Res, 1st Decade 10k per step, 2nd Decade 2k per step, 3rd Decade 400Ω per step	11837	8119	3	
A_2	Switch Assy, Res, 4th Decade 400Ω per step, 5th Decade 400Ω per step, 6th Decade 400Ω per step	11837	8142	3	
A_3	Switch Assy, Res, 7th Decade 400Ω per step	11837	8143	1	
R_{1-11}	Res, Fxd, Precision, 10k, Part of Assy A_1	11837	*	11	

* Replace entire Assy

Ckt Ref	Description	Mfr	ESI Part No.	Qty Used	Recm SP
R_{12-22}	Res, Fxd, Precision, 2k, Part of Assy A_1	11837	*	11	
R_{23-33}	Res, Fxd, Precision, 400Ω, Part of Assy A_1	11837	*	11	
R_{34-66}	Res, Fxd, Precision, 400Ω, Part of Assy A_2	11837	*	11	
R_{67-76}	Res, Fxd, Precision, 400Ω, Part of Assy A_3	11837	*	10	
R_{77-79}	Res, Fxd, Precision, 1k Part of Assy A_2	11837	*	3	
R_{80}	Res, Fxd, Precision, 1k, Part of Assy A_3	11837	*	1	
S_{1-3}	Switch, Rotary, Part of Assy A_1	11837	*	3	
S_{4-6}	Switch, Rotary, Part of Assy A_2	11837	*	3	
S_7	Switch, Rotary, Part of Assy A_3	11837	*	1	
	MISCELLANEOUS				
	Cap, Binding Post, Black	11837	1170	4	
	Cap, Binding Post, Gold	11837	1172	2	
	Binding Post	11837	1393	6	
	Dial	11837	7808	3	
	Dial	11837	7819	1	
	Dial	11837	8130	1	

* Replace entire Assy

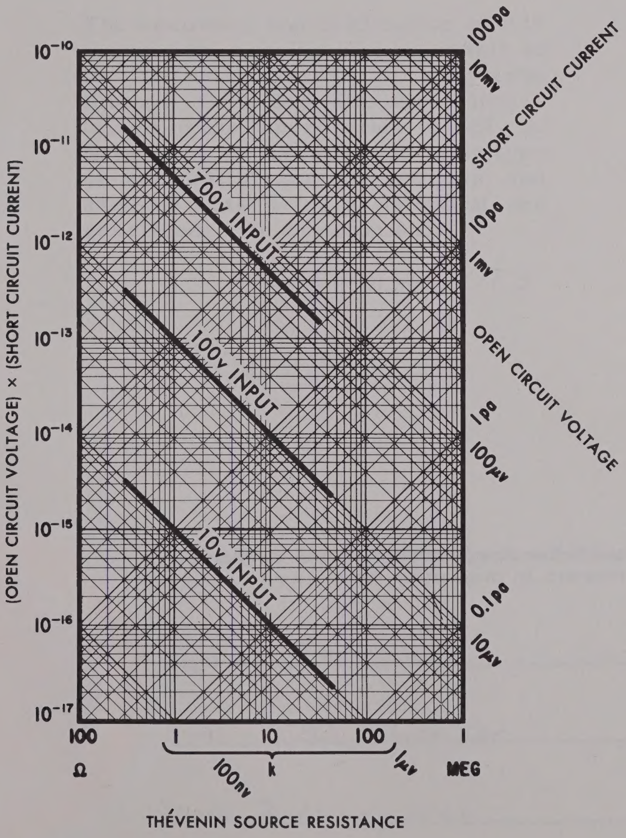
Ckt Ref	Description	Mfr	ESI Part No.	Qty Used	Recm SP
	Dial	11837	8131	2	
	Dust Cover	11837	1581	1	
	Knob, Bar	11837	1266	7	
	Probe Tip	11837	8145	2	
	Window	11837	7243	4	
	Window	11837	7242	3	

SECTION V

APPENDIX

When using the RV 722 in a measuring system, the selection of an appropriate detector is extremely important. ESI Engineering Bulletin No. 23, "A New Approach to Bridge Sensitivity", included in this appendix, explains in considerable detail the generator and detector requirements of bridge circuits. This material is directly applicable to the RV 722. In association with EB 23 the families of source describing points for RV 722 input voltages of 700 volts, 100 volts and 10 volts have been plotted on the graph below. Any detector whose curve falls below these families of source describing points will resolve at least 0.1 ppm for any of the input voltages indicated (700v, 100v or 10v). The ESI Model 800 Generator-Detector, whose detector curve is also plotted on this graph, will obviously resolve these voltages.

Also included in this appendix is Engineering Bulletin No. 29, "DC and Low Frequency AC Ratio Measurements". This paper discusses Kelvin-Varley calibration and other material that is applicable to the RV 722.



Certificate

MODEL RV 722
KELVIN-VARLEY VOLTAGE DIVIDER

The accuracy and calibration of this instrument are directly traceable to the National Bureau of Standards through Certified Standards maintained in the laboratories of ESI, or have been derived by the ratio type of self-calibration techniques and are guaranteed for a period of one year from date of shipment.

Serial No. 413073

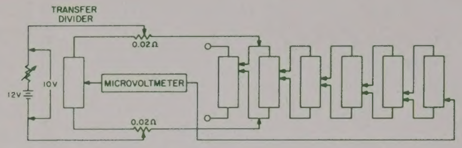
Electro Scientific Industries
7524 S.W. MACADAM • PORTLAND 19, OREGON

Signed T.A. Piper

Title Q.C. Inspector

Date 2 July 1964

The practical calibration of Kelvin-Varley dividers is accomplished with the circuit of Figure 1. The decade to be calibrated is connected in parallel with a ten-step standard divider through low-resistance lead-compensating potentiometers. The figure shows the connection for calibrating the second decade. In this circuit, the ESI Model SR 1010 Resistance Transfer Standard can serve as an exceptionally accurate reference standard divider, since its tap ratios can be calculated from resistance intercomparison measurements to a linearity of better than 1 part in 5 million.

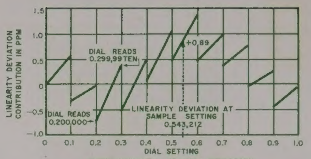


CONNECTION FOR CALIBRATION OF INDIVIDUAL DECADES

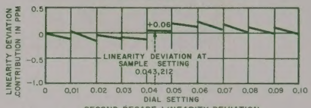
FIGURE 1. KELVIN-VARLEY CALIBRATION

A high-impedance microvoltmeter is used to read the difference between the Kelvin-Varley output and the standard divider tap. The lead-compensating potentiometers shown in Figure 1 are adjusted so that the microvoltmeter indicates no voltage difference between the standard and Kelvin-Varley dividers when both are set at their maximum or their zero settings. At each setting of the decade under test, two microvoltmeter readings are taken - - one with all the decades to the right set at zero, and one with all decades to the right set at maximum. The ratio of each reading to the applied voltage represents the deviation of the Kelvin-Varley from the standard, expressed as a fraction of the full-scale range of the decade under test. These readings are then corrected for the calibration of the standard and divided by the appropriate power of ten to convert them to linearity deviation contributions expressed as a fraction of full-scale for the whole divider.

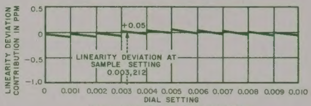
The contributions to linearity deviation from the various decades can be plotted as pairs of points joined by straight lines as in Figure 2. Note that the first and last reading for each decade has been made equal to zero by the adjustment of lead-compensating potentiometers, so that the plot for the decade will represent the deviation from perfect interpolation between the highest and lowest outputs that can be obtained from that decade and the decades to the right of it. The deviation at the ends of this range is included in the calibration of the next decade to the left. Thus, an important feature of this method is that the calibration includes the effect of all lead resistances.



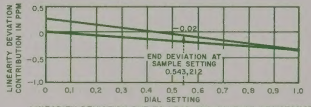
FIRST DECADE LINEARITY DEVIATION



SECOND DECADE LINEARITY DEVIATION



THIRD DECADE LINEARITY DEVIATION



LINEARITY DEVIATION DUE TO LEAD AND CONTACT RESISTANCE

TOTAL: −0.02 +0.89 +0.06 +0.05 = 0.98 PPM LINEARITY DEVIATION

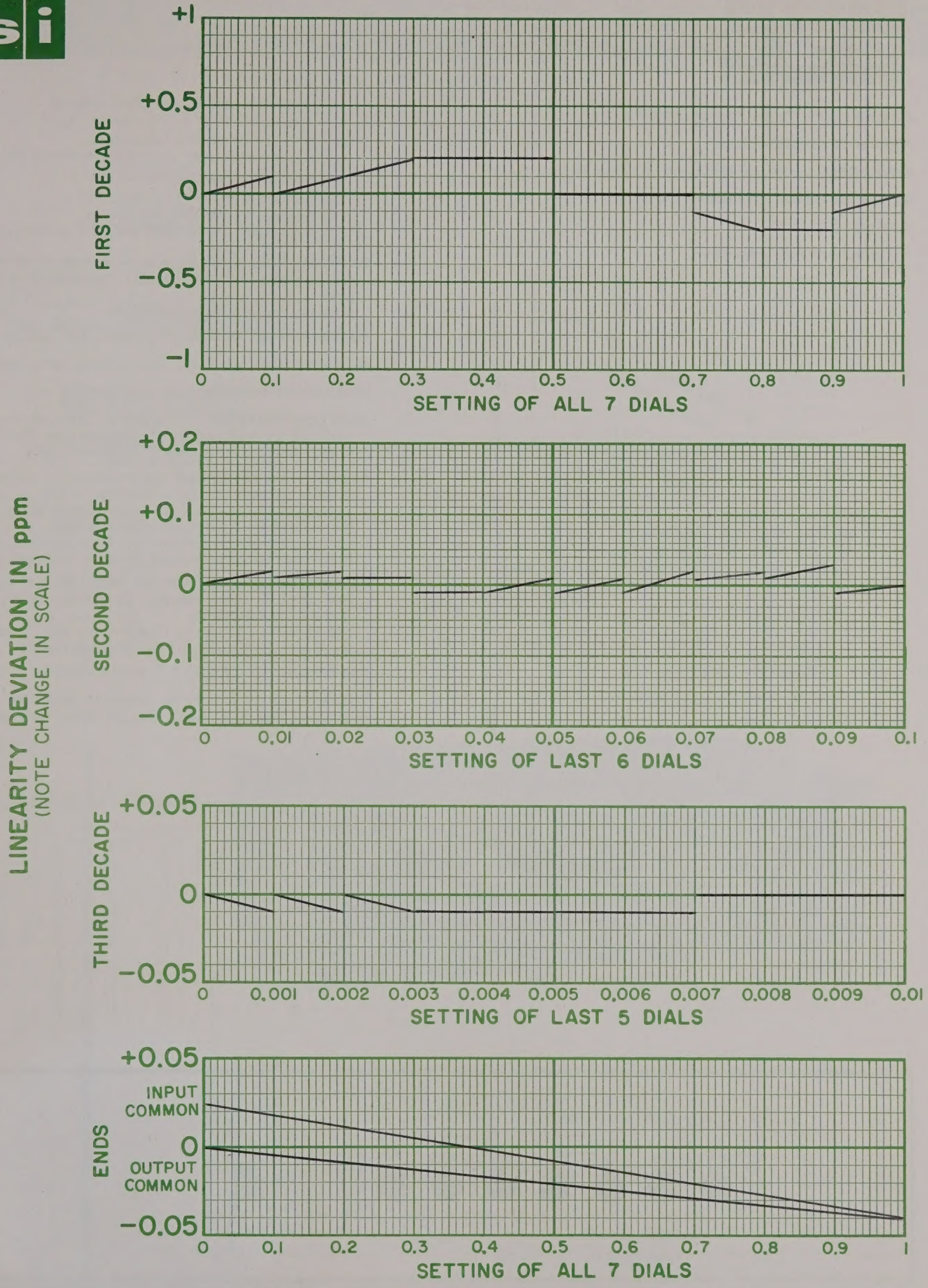
FIGURE 2. LINEARITY DEVIATION GRAPH

In reading such calibration graphs, the settings of all dials to the right of a given decade must be included in the interpolation along a line segment. In Figure 2, for example, at a setting of 0.543,212, the first decade graph reads +0.89 at 0.543,212, the third decade reads +0.05 at 0.003,212. The linearity deviation contributed by the last three decades is so small that it has been considered negligible and has not been plotted. Adding these readings gives an overall linearity deviation of +1.00 ppm at this setting, or an actual ratio of 0.543,213,00. This calculation calibrates the whole divider as an interpolator between its zero and full-scale output values.

If we want to calibrate the divider relative to the voltage at its input terminals, we can measure the two end voltage drops with the microvoltmeter and plot their effect as shown in the bottom graph in Figure 2. This shows an additional contribution to linearity deviation of -0.02 ppm at 0.543,212, making the total deviation relative to the input terminal +0.98 ppm at this setting, or an actual ratio of 0.543,212,98.

To increase the accuracy of the output voltage at low settings the output common terminal is connected to a point having approximately the same voltage as the output terminal at zero setting. The resulting curve is also shown in Figure 2. To find the output voltage accuracy add the -0.2 from this curve to give a linearity deviation of +0.8 ppm. The output accuracy in proportional parts of the output voltage is the linearity deviation divided by the setting. For the example this is 1.47 ppm.

MODEL RV 722 KELVIN - VARLEY VOLTAGE DIVIDER



23 °C
TEMPERATURE

Specifications

CIRCUIT: Kelvin-Varley Resistive Divider.

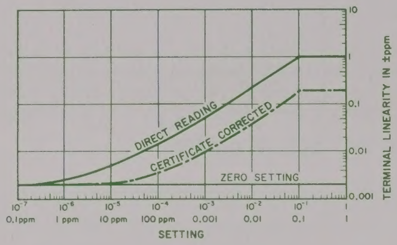
NUMBER OF DECADES: Seven.

RESOLUTION: 10,000,000 Divisions—0.1 ppm steps.

INPUT RESISTANCE: 100 Kilohms ±0.005%.

TERMINAL LINEARITY:

At time of final inspection:



Certificate Corrected

Settings of 0.1 to 1: ±0.2 ppm.

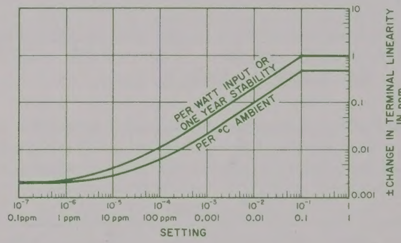
Settings below 0.1 improve to
$\pm\{0.2\text{ ppm } (10 \times \text{SETTING})^{2/3} + 0.002\text{ ppm}\}$.

Direct Reading

Settings of 0.1 to 1: ±1 ppm.

Settings below 0.1 improve to
$\pm\{1\text{ ppm } (10 \times \text{SETTING})^{2/3} + 0.002\text{ ppm}\}$.

Limit of changes in terminal linearity:



One Year Stability

Settings of 0.1 to 1: ±1 ppm.

Settings below 0.1 improve to
$\pm\{1\text{ ppm } (10 \times \text{SETTING})^{2/3} + 0.002\text{ ppm}\}$.

Temperature Coefficient (20°C to 30°C)

Settings of 0.1 to 1: ±0.5 ppm/° C.

Settings below 0.1 improve to
$\pm\{0.5\text{ ppm } (10 \times \text{SETTING})^{2/3} + 0.002\text{ ppm}\}/{}^\circ\text{C}$

Power Coefficient

Settings of 0.1 to 1: ±1 ppm/watt.

Settings below 0.1 improve to
$\pm\{1\text{ ppm } (10 \times \text{SETTING})^{2/3} + 0.002\text{ ppm}\}/\text{watt}$

SWITCHES: Solid silver alloy rotor and stator contacts. Four independent electrically parallel wiping surfaces per switch contact.

Silicone treated ceramic insulation.

MAXIMUM INPUT POWER: Five watts (700 volts d c or rms).

MAXIMUM INPUT VOLTAGE: 700 volts rms, 1000 volts peak.

BREAKDOWN VOLTAGE: 1000 volts peak to case.

ZERO COMPENSATION: The common output terminal is compensated for lead and switch resistance, so that the output at zero setting is less than 0.004 ppm of input.

CALIBRATION FACILITIES: Input terminals for individual decades are provided for calibration of each decade against a standard divider with ten equal steps.* When calibrated for immediate use, the short-term accuracy is much better than any long-term certification. Measurements accurate to better than 0.2 ppm terminal linearity are possible.

ACCESSORIES RECOMMENDED: ESI Model SR 1010 10k per step Resistance Transfer Standard (precision 10-step standard divider) for calibration.

ESI Model LC 875 Lead Compensator (for balancing lead resistances in divider calibration comparisons).

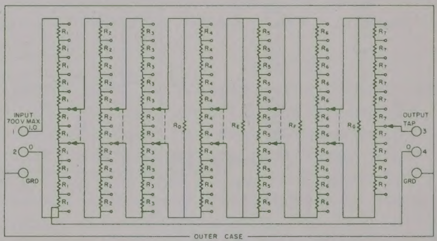
DIMENSIONS: 5.23″ high x 7.1″ deep x 19″ wide.

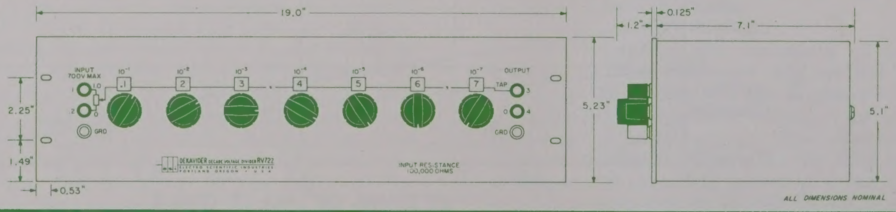
WEIGHT: 12.5 lbs net, 18 lbs packed for shipping.

*Procedure described in ESI "Design Ideas," Volume 1, No. 1, January, 1960.

CIRCUIT DIAGRAM:

R_1	R_2	R_3	R_D	R_4	R_E	R_5	R_F	R_6	R_G	R_7
10k	2k	400Ω	1k	400Ω	1k	400Ω	1k	400Ω	1k	400Ω





Electro Scientific Industries
7524 S. W. Macadam Avenue, Portland 19, Oregon

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**BRIDGES
AND
ACCESSORIES**

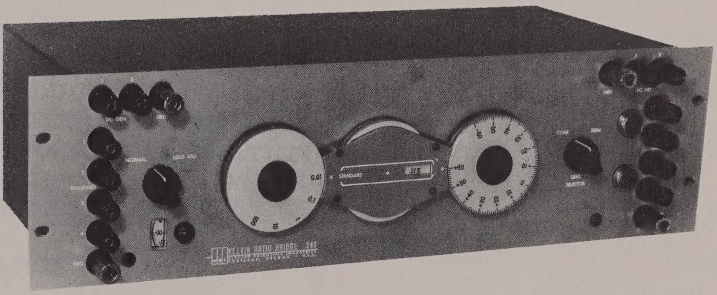
JANUARY 1963

MODEL
240

Instruction Manual

KELVIN RATIO BRIDGE

T.O. 33-A1-12-449-1



SERIAL NUMBER ____________

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LITHO IN U.S.A.

TABLE OF CONTENTS

I DESCRIPTION AND SPECIFICATIONS

- 1.1 DESCRIPTION
- 1.2 SPECIFICATIONS
- 1.3 ACCESSORY REQUIREMENTS

II OPERATING INSTRUCTIONS

- 2.1 CONTROLS, INDICATORS, AND TERMINALS
- 2.2 BASIC OPERATING PROCEDURE
- 2.3 PRECISION RESISTANCE CALIBRATION PROCEDURES
- 2.4 GENERATOR-DETECTOR CONNECTIONS
- 2.5 UNKNOWN AND STANDARD RESISTOR CONNECTIONS
- 2.6 LEAD RESISTANCE COMPENSATION ADJUSTMENT

III THEORY OF OPERATION

- 3.1 GENERAL
- 3.2 STANDARD MULTIPLIER RATIOS
- 3.3 LEAD RESISTANCE COMPENSATION ADJUSTMENT
- 3.4 DEVIATION DIALS
- 3.5 GUARDING
- 3.6 ACCURACY ANALYSIS

IV CALIBRATION

- 4.1 INTRODUCTION
- 4.2 INCREMENTAL ACCURACY
- 4.3 MAIN RATIO CALIBRATION
- 4.4 AUXILIARY RATIO CALIBRATION
- 4.5 YOKE RESISTANCE

V MAINTENANCE

- 5.1 PREVENTIVE MAINTENANCE
- 5.2 TROUBLE SHOOTING
- 5.3 DIAGRAMS AND PHOTOGRAPHS
- 5.4 PARTS LIST

WARRANTY

SECTION I

DESCRIPTION AND SPECIFICATIONS

1.1 DESCRIPTION

The MODEL 240 KELVIN RATIO BRIDGE is designed to compare an unknown resistor with a standard resistor very accurately. The standard multiplier dial selects one of five multiplier ratios from 0.01 to 100. This permits comparison of resistors in the ratio of 10:1 or 100:1 as well as 1:1. The bridge deviation dial reads the difference between the actual ratio and the nominal ratio of the two resistors in percent or in parts per million.

Four-terminal connections are provided for both the standard and the unknown. The lead selector switch permits the option of connecting the bridge to the unknown resistor by means of binding posts or by shielded connectors, both of which are provided on the front panel of the bridge.

1.2 SPECIFICATIONS

Multiplier Ratios: 0.01, 0.1, 1, 10, 100

Multiplier Accuracy: ±0.001% on the 1:1 range, ±0.005% on all other ranges, at 25°C with negligible power dissipation (100 mw).

Temperature Coefficient of Resistors: ±5 ppm/°C from 10°C to 50°C

Power Coefficient of Resistors: ±0.1 ppm/mw. No permanent damage below 1 watt.

Lead Resistance: A panel control compensates for resistance up to 100 milliohms in the test leads to the unknown.

Guarding: The bridge is designed to prevent leakages from appearing across high resistance standard or unknown resistors.

Deviation Ranges:

RANGE		EACH DIAL DIVISION	
MIN	MAX	PPM	%
-60 ppm	60 ppm	1	0.0001
- 0.06%	0.06%	10	0.001
- 0.6%	0.6%	100	0.01

Deviation Accuracy: ±1 dial division.

Deviation Resolution: 1/4 dial division.

Dimensions: 5-1/4 inches high, 19 inches wide, 7 inches deep.

Weight: 11 lbs net.

1.3 ACCESSORY REQUIREMENTS

To utilize the full capabilities of the MODEL 240 KELVIN RATIO BRIDGE it is necessary to choose an adequate dc generator and detector. Standard resistors must be available which are suitable for the measurement to be made. ESI combination generator-detector models are available with all the requirements listed below as built-in features. The ESI MODEL RS 925 DECADE RESISTANCE STANDARD was designed specifically as a wide-range working standard for the Model 240 bridge, and other ESI reference and transfer standards are available.

1.3.1 GENERATOR REQUIREMENTS

a) The dc generator (which may be a battery) must be well insulated from ground, and preferably guarded, with a minimum leakage resistance of 10^{10} ohms from one terminal and 10^{12} ohms from the other terminal to ground.

b) Generator switching must be guarded so that there are no measurable* leakage currents to ground in either the on or the off position. (*Measurable at the maximum sensitivity of the detector used.)

c) The generator should be power-limited to a maximum of one watt, by a series resistance of at least $\frac{(E_{max})^2}{4}$ for a generator open-circuit voltage of E_{max}.

d) Several different generator voltages, each with an appropriate limiting resistance, should be available for selection to yield maximum sensitivity in measuring different resistance values. If batteries are to be used the following typical combinations are suggested. The series limiting resistor must be capable of dissipating four watts.

Maximum Voltage (open circuit) (approx.)	Series Limiting Resistor (approx.)	Maximum Current (short circuit) (approx.)
1.5 volts	0.56 ohm	2.7 amps
6 volts	10 ohm	0.6 amp
22.5 volts	120 ohm	190 ma
90 volts	2.2 kilohms	41 ma
300 volts	22 kilohms	14 ma

e) If a line-operated dc generator is used with a modulator type dc detector, the generator ac ripple output and the ac voltage from the output terminals to ground should be low enough to avoid ac interference problems in the dc detector. (The amount which can be tolerated depends upon the detector used.)

1.3.2 DETECTOR REQUIREMENTS

a) For utilizing the full accuracy of the bridge, the detector should be capable of detecting dc signals very close to theoretical noise level at a source resistance in the vicinity of 10 kilohms. It must operate well with source resistances from 100 ohms to 1 megohm.

b) The detector should be relatively insensitive to interference from ac signals into its input; the amount which can be tolerated will dictate the care which must be taken in shielding the measurement setup and selecting the generator to be used.

c) A detector with internally grounded input may be used for all normal bridge applications, however, a detector with floating input will allow certain alternate modes of operation:

  1) If the detector can be operated with its low input terminal insulated from ground, but essentially at ground potential, a connection for lower sensitivity to ac pickup in low resistance measurements is possible.

  2) If the detector can be operated with its low input terminal at a high dc voltage above ground without observable indication (thorough guarding required), a connection for higher accuracy and sensitivity in high resistance measurements is possible.

d) A shorting switch should be provided to momentarily short the detector input when turning the generator on and off, for measurements in which reactive transients are found to occur.

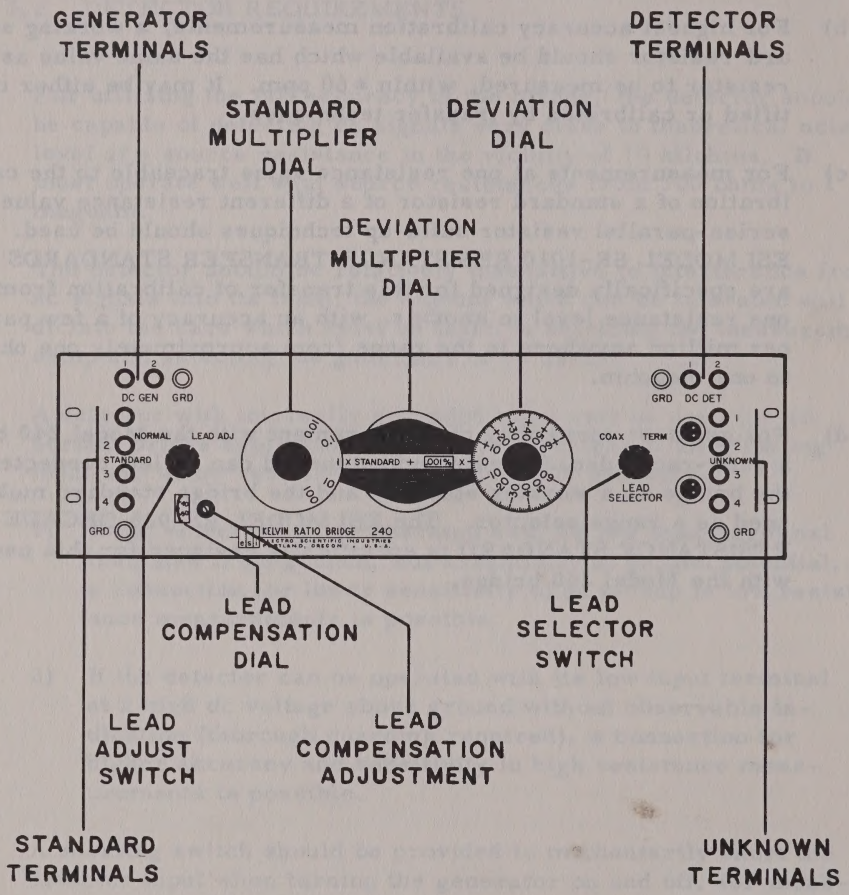
1.3.3 STANDARD RESISTOR REQUIREMENTS

a) A four-terminal, shielded (guarded) construction is recommended for all resistance standards to be used with the bridge; the standard preferably should be four-terminal below 10 kilohms and guarded (three-terminal, shielded) above 10 kilohms.

b) For highest accuracy calibration measurements, a working standard resistor should be available which has the same value as the resistor to be measured, within ±60 ppm. It may be either certified or calibrated by transfer techniques.

c) For measurements at one resistance value traceable to the calibration of a standard resistor of a different resistance value, series-parallel resistor build-up techniques should be used. ESI MODEL SR-1010 RESISTANCE TRANSFER STANDARDS are specifically designed for this transfer of calibration from one resistance level to another, with an accuracy of a few parts per million anywhere in the range from approximately one ohm to one megohm.

d) For greatest versatility of measurement with the Model 240 bridge, a wide-range decade resistance standard can be left connected to the bridge as a working standard and the bridge standard multiplier used as a range selector. The ESI MODEL RS-925 DECADE RESISTANCE STANDARD is specifically designed for this use with the Model 240 bridge.



MODEL 240 KELVIN RATIO BRIDGE

PANEL CONTROLS

SECTION II

OPERATING INSTRUCTIONS

2.1 CONTROLS, INDICATORS, AND TERMINALS

Standard Multiplier Dial: The left-hand dial selects from one of five multiplying factors which can be used to compare resistors in the ratios; 1:100, 1:10, 1:1, 10:1, or 100:1. The multiplying factor appears to the left of the words X STANDARD.

Deviation Multiplier Dial: The center dial selects one of three deviation multipliers: 1 ppm, .001%, or .01%. The selected multiplying factor appears in a window to the left of the deviation dial.

Deviation Dial: The right-hand dial times the Deviation Multiplier gives the percent or ppm deviation of the unknown from the product of the standard and the standard multiplier.

LEAD ADJUST Switch: The switch on the left side of the bridge selects either the bridge circuit used for normal operation or that used for adjusting the lead compensator.

Lead Compensation Adjustment: The screw driver control on the left side of the bridge adjusts the circuit to compensate for test lead resistance. The associated dial indicates the approximate test lead resistance in milliohms.

LEAD SELECTOR Switch: The switch on the right-hand side of the bridge selects the unknown terminals. In the COAX position terminals 1 and 4 are connected to the shielded connectors. In the TERM position terminals 1 and 4 are connected to the binding posts. Terminals 2 and 3 are always connected to both the shielded connectors and the binding posts.

DC GEN Terminals: The upper left terminals of the bridge are for attaching an external generator.

DC DET Terminals: The upper right terminals are for attachment of an external detector. In normal bridge operation the number one detector terminal is connected to ground either at this set of terminals or at the detector.

STANDARD Terminals: The terminals along the left-hand side of the bridge are for connection to a four-terminal resistance standard. The adjacent GRD terminal is provided for shield connection.

UNKNOWN Terminals: The terminals along the right-hand side of the bridge are for connection to the resistor to be measured. Shielded connectors are provided for use with ESI Kelvin Klip test leads. Binding post terminals are provided for use with four separate test leads. Since terminals 2 and 3 are permanently connected to the shielded connectors, the LEAD ADJ switch can be set to TERM and the Kelvin Klips used for the number 2 and 3 terminal connections with two wires brought out from terminals UNKNOWN 1 and 4.

2.2 BASIC OPERATING PROCEDURE

The MODEL 240 KELVIN BRIDGE is factory calibrated for better than rated accuracy under laboratory conditions. For maximum accuracy an ambient temperature of 25°C and a relative humidity of less than 50% should be maintained. The power input to the bridge should be reduced to one-tenth maximum power or less if adequate detector sensitivity is available.

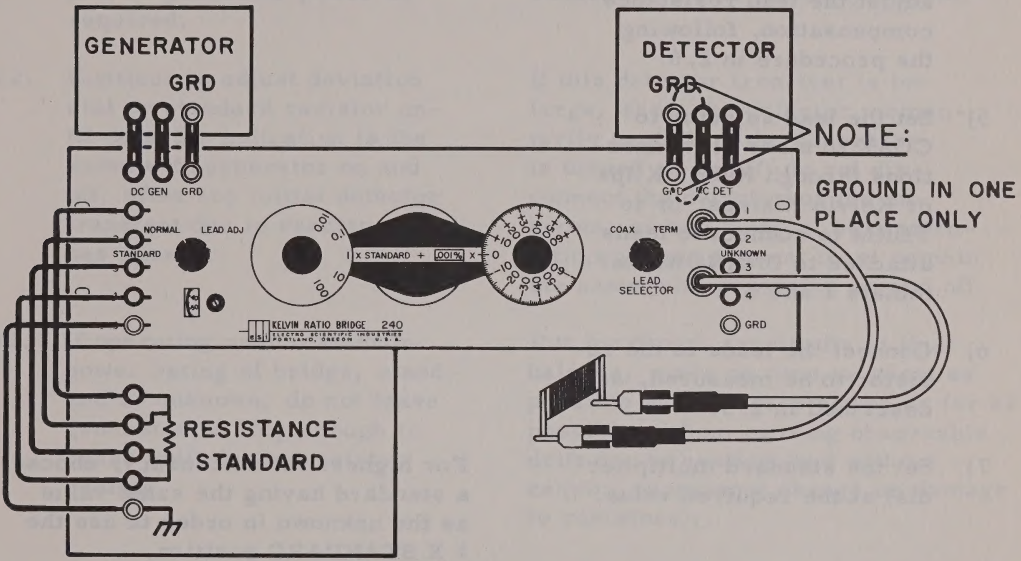


FIG. 2.2

1) See that the generator and detector are connected to the bridge as specified in 2.4.

2) Connect a suitable fixed or variable standard resistor to the STANDARD terminals of the bridge as described in 2.5.

WARNING: Limit the generator to one watt maximum; ESI generator models feature internal power limiting.

For maximum versatility, a wide-range decade standard such as the ESI Model RS-925 can be left connected as a working standard for practically all measurements.

3) Connect the UNKNOWN test leads to the bridge as described in 2.5.	For two-terminal resistors, use Kelvin Klips or Kelvin Klamp sets. For four-terminal resistors, use separate leads to UNKNOWN terminals 1 and 4, together with either the Kelvin Klip leads or separate leads to UNKNOWN 2 and 3.
4) If the leads for UNKNOWN terminals 2 and 3 are different from those last used, adjust the lead resistance compensation, following the procedure in 2.6.	
5) Set the lead selector to COAX to make all connections through Kelvin Klips or Kelvin Klamps, or to TERM to connect to leads attached to UNKNOWN terminals 1 and 4.	
6) Connect the leads to the resistor to be measured, as described in 2.5.	
7) Set the standard multiplier dial at the required value.	For highest ratio accuracy, choose a standard having the same value as the unknown in order to use the 1 X STANDARD position.
8) Set the detector sensitivity to an appropriate initial value, and adjust its zero adjustment if the indication is not near zero.	Do not short-circuit or open-circuit detector input when making its zero adjustment.
9) Turn on the generator.	Use low power for the initial balance.
10) a. If the standard resistor is fixed, or adjusted to a preset value, adjust the deviation dial and deviation multiplier for a detector null.	

	b. If the value of the unknown is to be read on a calibrated adjustable standard resistor, set the deviation multiplier at 1 ppm and the deviation dial at 0, and adjust the standard resistor for a detector null.	
11)	As the null is approached, increase detector sensitivity and/or generator power as required.	When detector sensitivity is increased, turn off generator and recheck detector zero adjustment.
12.	Continue to adjust deviation dial or standard resistor until detector indication is the same with generator on and off, after any initial detector transient due to reactance has passed.	If this detector transient is too large, short the detector momentarily each time the generator is turned on or off; do not disconnect the detector or the unknown, as any thermal or electrolytic voltages present must remain the same with generator on and off.
13.	If operating near maximum power rating of bridge, standard or unknown, do not leave generator on long enough to cause drift due to resistor heating.	For maximum sensitivity at final balance, make on time as short as possible and increase power as far as possible without causing observable drift due to heating (and without causing permanent change or damage to resistors).

2.3 PRECISION RESISTANCE CALIBRATION PROCEDURES

2.3.1 TRACEABLE RESISTANCE CALIBRATION

In precision resistance measurement, the calibration of any resistor must be traceable through a succession of precise resistance comparisons to the unit of resistance maintained as a national or international standard. The resolution and short-term stability of the Model 240 bridge make it possible to compare two like resistance values to an accuracy better than two parts per million.

A standard resistor can be compared with a parallel-connected group of resistors yielding the same resistance value. The same group of resistors can then be connected in series to provide a calibrated standard of a different resistance value. ESI Model SR 1010 Resistance Transfer Standards are designed to make this series-parallel transfer with negligible loss in accuracy. The use of a set of Model SR 1010 transfer standards with the Model 240 bridge will permit calibration of resistors from an ohm to a megohm with an accuracy of a few parts per million, relative to a Thomas pattern one-ohm reference standard certified by the National Bureau of Standards.

The comparison of like resistance values required for this type of calibration can be made independent of the absolute accuracy and long-term stability of the bridge ratio by using either of the two methods described in the following sections.

2.3.2 RESISTANCE COMPARISON BY THE INTERCHANGE METHOD

In the comparison of two nominally equal resistors by the interchange method, the calculated deviation from the standard resistor of the unknown resistor will normally be accurate to within one or two ppm for resistors matched within 60 ppm.

Follow the basic procedure of Section 2.2 to perform the following pair of measurements:

1) With the known resistor connected to the STANDARD terminals and the unknown resistor connected to the UNKNOWN terminals, balance the bridge and read the deviation dial. Call this reading d_1.

2) With the unknown resistor connected to the STANDARD terminals and the known resistor connected to the UNKNOWN terminals, balance the bridge and read the deviation dial. Call this reading d_2.

3) Calculate $\frac{d_1 - d_2}{2}$. This is the deviation of the unknown resistor from the standard resistor. To obtain the deviation of the unknown resistor from nominal value, add to this calculated value the deviation of the standard resistor from nominal value.

2.3.3 RESISTANCE COMPARISON BY THE SUBSTITUTION METHOD

In the comparison of two nominally equal resistors by the substitution method, a working standard resistor is left connected to the STANDARD terminals of the ratio bridge while two measurements are made -- one with an accurately known resistor connected to the UNKNOWN terminals, the other with the unknown resistor connected to them.

This method is particularly convenient when a decade standard such as the ESI Model RS-925 is used, since it makes possible direct dial readings corrected to agree with the calibration of the known resistor and expressed either in ohms or in ppm deviation from the nominal value.

This method is based on the fact that either the deviation dial or the decade standard can be used as a calibration adjustment to make the other one read exactly the value of a known resistor connected to the unknown terminals; with the reading exactly correct at this setting, it will be correct within one or two ppm at all nearby settings (to at least ± 60 ppm).

Follow the basic procedure of Section 2.2 to perform either of the following pairs of measurements:

a) To read value in ohms:

1. With the known resistor connected to the unknown terminals, set the decade standard to its given resistance value, then use the deviation dial to balance the bridge.

2. Disconnect the known resistor and connect the unknown resistor.

3. Leaving the deviation dial setting alone, use the decade standard adjustment to balance the bridge. Its reading will be the value of the unknown resistor.

b) To read deviation from nominal value:

1. With the known resistor connected to the unknown terminals, set the deviation dial to its given deviation from nominal value, then use the decade standard dials to balance the bridge.

2. Disconnect the known resistor and connect the unknown resistor.

3. Leaving the decade standard setting alone, use the deviation dial to balance the bridge. Its reading will be the deviation of the unknown resistor from nominal value.

2.3.4 COMPARISON OF LOW RESISTANCE VALUES

When the values of the standard and unknown resistors are so low that the voltage drop in the "yoke" circuit connecting them in series becomes an appreciable fraction of the sum of the voltage drops in the standard and the unknown resistors, the accuracy of the "yoke" or "auxiliary" ratio in the comparison bridge becomes important (refer to Theory Section 3.6). The accuracy of the auxiliary ratio in the Model 240 bridge is such that this effect can be neglected for resistance values of an ohm or higher, unless the yoke resistance is unusually high.

When the auxiliary ratio accuracy cannot be neglected, the ratio can be adjusted to exactly match the main ratio by adding a small amount of resistance in series with the UNKNOWN 3 or STANDARD 3 terminal. This resistance should be adjusted so that the bridge remains balanced when the lead at either UNKNOWN 4 or STANDARD 4 is disconnected and reconnected.

The need for this adjustment can be minimized in some instances by making an external yoke connection of lower resistance, as discussed in Section 2.5.3 on measurements at high current. The effect of auxiliary ratio accuracy also becomes relatively unimportant in either the interchange method (Section 2.3.2) or the substitution method (Section 2.3.3) of comparing two equal resistors if the yoke resistance can be made the same for both measurements -- in this case both readings will be affected the same amount by any inaccuracy in the auxiliary ratio, and the error will be cancelled.

2.4 GENERATOR-DETECTOR CONNECTIONS

The Model 240 Bridge is designed for use with a grounded detector having a fixed input resistance, and a floating generator or set of batteries providing a wide range of voltages and currents. The normal connections described in the following sections are suitable for all normal bridge applications. They give the bridge its full accuracy over a very wide range of resistance from low value four-terminal resistors to high value guarded or three-terminal resistors. The alternate connections described in Section 2.4.3 are for certain specific situations and should not be used for general purpose use of the bridge.

2.4.1 NORMAL GENERATOR CONNECTIONS

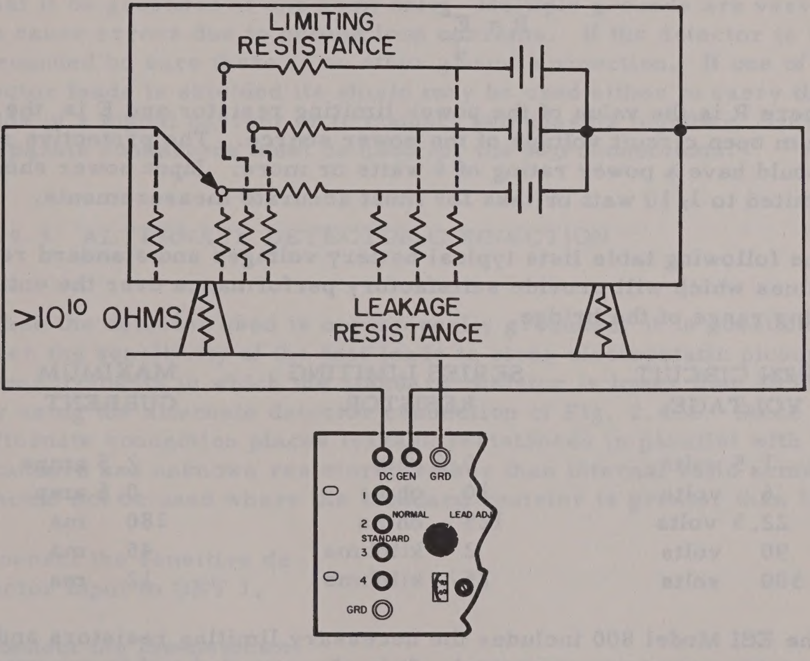


FIG. 2.4.1

For high resistance measurements the DET 1 terminal of the bridge must be grounded, requiring that the generator be well isolated from ground (see Fig. 2.4.1). The leakage resistance from GEN 2 to ground will then appear across a 10 kilohm arm of the bridge where a leakage resistance of 10^{10} ohms will cause a ratio error of only 1 ppm. Any leakage resistance from the GEN 1 terminal to ground will appear across the range resistor which is 1 megohm at the highest range.

In some installations the ambient humidity may make it difficult to maintain bridge dependability without guarding. Therefore, it is recommended that the generator or battery be mounted so that all leakage paths through insulating materials return to a guard chassis which is connected to the GEN 2 terminal. Then these leakage resistances will not appear in the measurement. Neither will there be any leakage from GEN 1 to ground, external to the bridge.

For bridge protection and reliability it is necessary that the maximum available power to the bridge be limited to one watt. This is accomplished by placing a resistor in series with the power source. The value of this resistor can be calculated from the formula

$$R = \frac{E^2}{4}$$

where R is the value of the power limiting resistor and E is the maximum open circuit voltage of the power source. The protective resistor should have a power rating of 4 watts or more. Input power should be limited to 1/10 watt or less for most accurate measurements.

The following table lists typical battery voltages and standard resistor values which will provide satisfactory performance over the entire operating range of the bridge.

OPEN CIRCUIT VOLTAGE	SERIES LIMITING RESISTOR	MAXIMUM CURRENT
1.5 volts	0.6 ohm	2.5 amps
6 volts	10 ohms	0.6 amp
22.5 volts	125 ohms	180 ma
90 volts	2 kilohms	45 ma
300 volts	25 kilohms	12 ma

The ESI Model 800 includes the necessary limiting resistors and has a variable output power control. It is also guarded and is recommended for use with the 240 bridge.

2.4.2 NORMAL DETECTOR CONNECTION

For normal Model 240 Kelvin Ratio Bridge applications, it is suitable to connect the low or grounded input terminal to the detector to DET 1 and the sensitive or high input to DET 2. If the detector is sensitive to interference from ac pickup, the lead from DET 2 should be shielded.

It is advisable that the bridge always be grounded rather then floating. If the bridge is floating it is very difficult to determine what the effects of the leakage resistances are on the measurement. By proper grounding, however, the effects not only can be determined but minimized as well. Generally, the DET 1 terminal is the most desirable corner of the bridge to have grounded.

While it is important that the bridge be grounded, it is equally important that it be grounded at one point only. Multiple grounds are very likely to cause errors due to ground loop currents. If the detector is internally grounded be sure there is no other ground connection. If one of the detector leads is shielded its shield may be used either to carry the grounded side of a signal current or to connect two chassis together, but not both -- separate conductors must be used for the two connections.

2.4.3 ALTERNATE DETECTOR CONNECTION

When the detector used is not internally grounded, it is possible to reduce the sensitivity of the test leads to stray electrostatic pickup, for measurements in which the standard resistor is lower than 10 kilohms, by using the alternate detector connection of Fig. 2.4.2. Since this alternate connection places leakage resistances in parallel with the standard and unknown resistors, rather than internal ratio arms, it should not be used where the standard resistor is greater than 10 kilohms.

Connect the sensitive detector input to DET 1.

Connect the low detector input to DET 2.

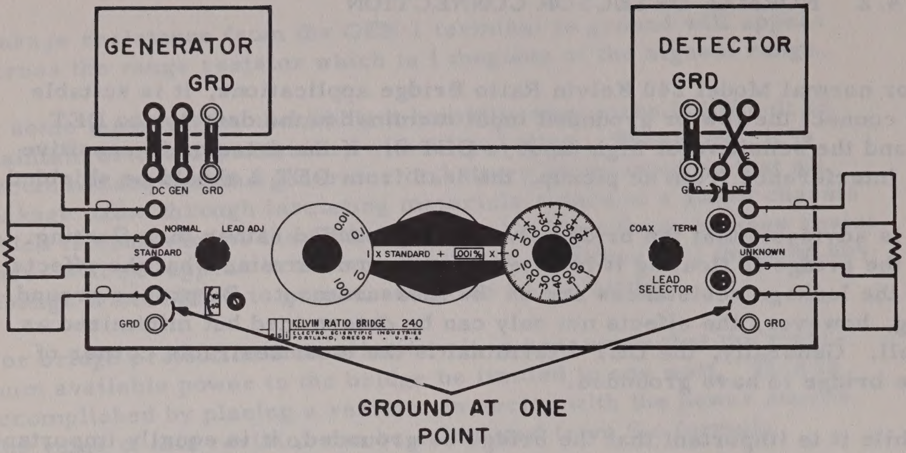


FIG. 2.4.3

Connect a large capacitor from DET 2 to GRD if the low detector input is not already well by-passed internally.

Be careful that there is no dc connection from this lead to ground, as this would short the yoke ratio, converting it to a single ratio bridge, producing errors due to lead resistance.

Connect terminal 4 of either the UNKNOWN or STANDARD side to the adjacent GRD.

2.4.4 GENERATOR-DETECTOR INTERCHANGE

For comparing two resistors having a very high resistance value, a higher voltage can be applied to the standard and unknown resistors, and the bridge sensitivity thereby increased, by interchanging the generator and the detector. This connection may also be useful in other applications where it is desirable to have the same voltage applied to the standard and the unknown; the usual connection makes their currents the same; on ranges higher or lower than 1 X STANDARD, the relative power dissipated by the standard and the unknown will be interchanged by the generator-detector interchange. (The normal connection applies the greater power to the larger resistance. The interchanged connection applies the greater power to the smaller resistance.)

If the detector used is sufficiently insulated from ground, the generator lead connected to the DET 2 terminal of the bridge should be grounded (see Section 1.3.2, paragraph c 2). However, if the detector is designed to operate with one of its terminals grounded the generator must be floated. Which GEN terminal should be connected to the grounded detector lead will depend on the multiplier used.

2.5 UNKNOWN AND STANDARD RESISTOR CONNECTIONS

2.5.1 BASIC CONNECTIONS

The 240 bridge is designed for making four-terminal connections to the standard and unknown resistors. On the standard side four binding posts are provided for four separate leads to the standard resistor. Binding posts are also provided on the unknown side as are shielded connectors for using two shielded pairs of wires. On each side the leads from terminals 1 and 2 are to be connected to one end of the resistor and the leads from terminals 3 and 4 to the other end, as shown in Fig. 2.5.1.

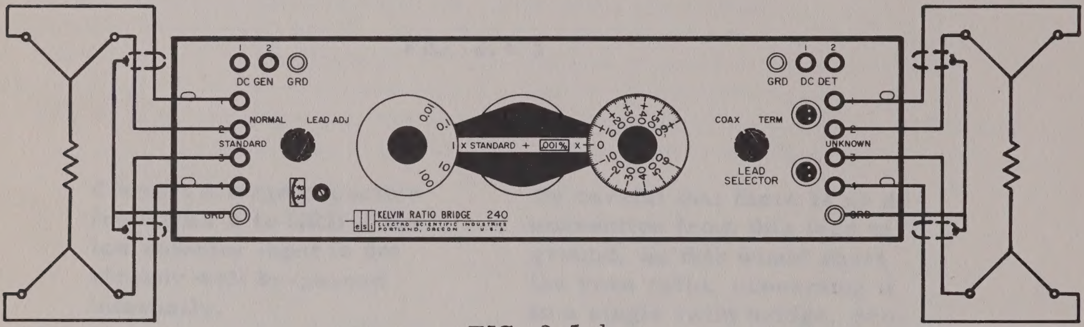


FIG. 2.5.1

It is advisable to use shielded leads for connecting to the unknown and standard resistors. The shields should be connected to the bridge ground. This not only prevents leakage between the leads from appearing in shunt with the standard or unknown resistor, it also reduces ac pickup which may be a problem when an electronic detector is used. Since leakage between terminals 1 and 2, or 3 and 4 will not affect the measurement each pair may be enclosed in the same shield. However, leakage between the enclosed leads and the shield will appear across internal bridge arms, thus it is necessary that the leads be adequately insulated from the shield. ESI KELVIN KLIPS (four-terminal connectors) or Belden 8422 cable is recommended for this application.

In connecting the standard and unknown resistors it is necessary to consider the effects of the lead resistances. The resistance of the lead connected to terminal 1 on both the standard and unknown side of the bridge is in series with the generator and will not affect the measurement accuracy. The resistance of the lead connected to terminal STANDARD 2 appears in series with a 10 kilohm bridge arm. This will cause a 1 ppm ratio error for each 10 milliohms of lead resistance. On the unknown side the lead compensation adjustment makes it possible to compensate for lead resistances under 100 milliohms in series with UNKNOWN 2 and 3. Lead resistance in series with terminals STANDARD 3 and 4, and UNKNOWN 3 and 4 will not be critical except for low valued resistance measurements, see Sections 2.3.4 and 3.6. When making low valued resistance measurements the connections shown in Fig. 2.5.4 should be used to reduce the yoke resistance. The yoke resistance as referred to throughout this manual is the resistance between terminal STANDARD 4 and UNKNOWN 4 plus the resistance of the leads connected to these two terminals, including the leads inside four-terminal standard and unknown resistors.

As an alternate connection for high resistance measurements, where the Kelvin bridge advantages are not needed, the pair of leads to each end of each resistor may be replaced by a single lead, and terminal 1 connected to 2, and 3 connected to 4, at the bridge. There is normally little need for this connection, however, since the Kelvin Klip leads or other test lead pairs used for low resistance measurements can be used equally well for high resistance measurements.

2.5.2 GUARDED UNKNOWN AND STANDARD RESISTOR CONNECTIONS

The 240 is so designed that internal leakages will not appear in shunt with either the resistor under test or the standard. This makes it possible to measure very high resistance. However, it is necessary that the resistor under test is not subject to external leakage effects. When a resistor is mounted between two terminals on an insulating block, the leakage of the block shunts the resistor. When separate insulators are mounted on a conducting support, however, as illustrated in Fig. 2.5.2a, the leakages can be separated from the resistor.

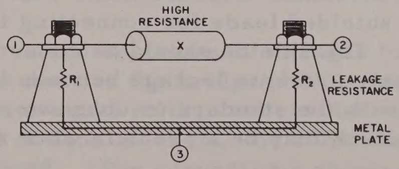


FIG. 2.5.2a

When the third terminal (the case or mounting plate) is connected to the Kelvin bridge as shown in Fig. 2.5.2b the leakages are placed across other arms of the bridge circuit. Leakage resistances R_2 and R_4

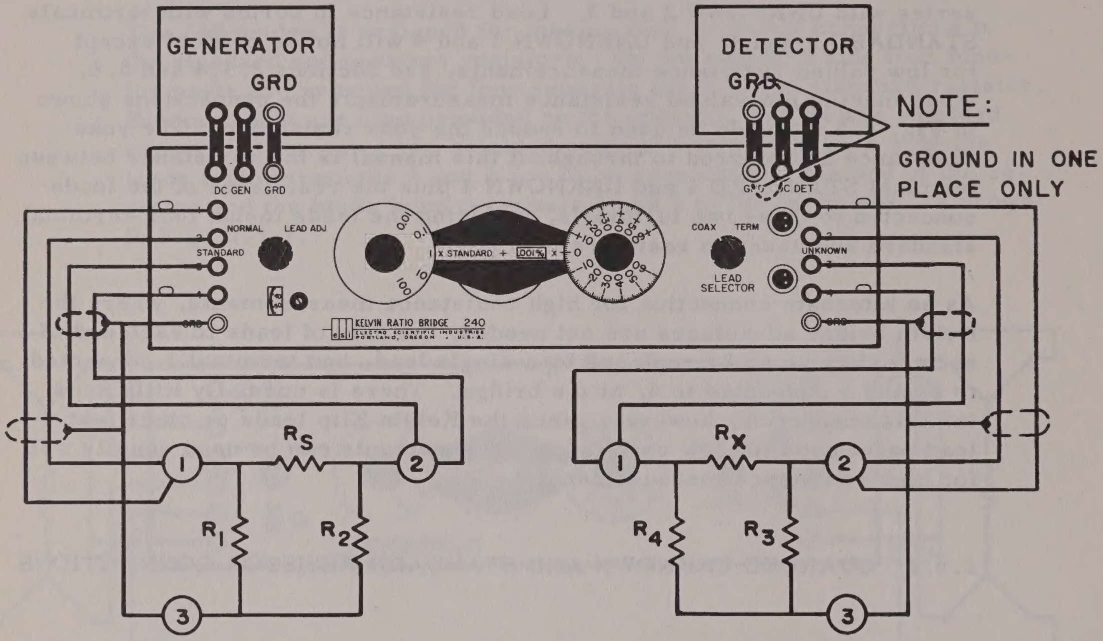


FIG. 2.5.2b

are essentially across the detector and will cause no error. Leakage resistance R_1, will be across a 10 kilohm internal bridge arm. This means R_1 must be greater than 10^{10} ohms before it can be considered as causing a negligible error (less than 1 ppm). Leakage resistance R_3 must be greater than 10^{10} ohms times the standard multiplier setting to have a negligible effect.

When making high resistance measurements with the 240 bridge it is advisable to use shielded leads for connecting to the unknown and standard resistors. The shields should be connected to the bridge ground. This not only prevents leakage between the leads from appearing in shunt with the standard or unknown resistor, it also reduces ac pickup which may be a problem when an electronic detector is used.

2.5.3 CONNECTIONS FOR RESISTANCE MEASUREMENTS AT HIGH CURRENT

To measure low valued resistors using a high current, an external current loop should be formed as shown in Fig. 2.5.3. This method will also permit a lower yoke resistance to be used than that internal to the bridge.

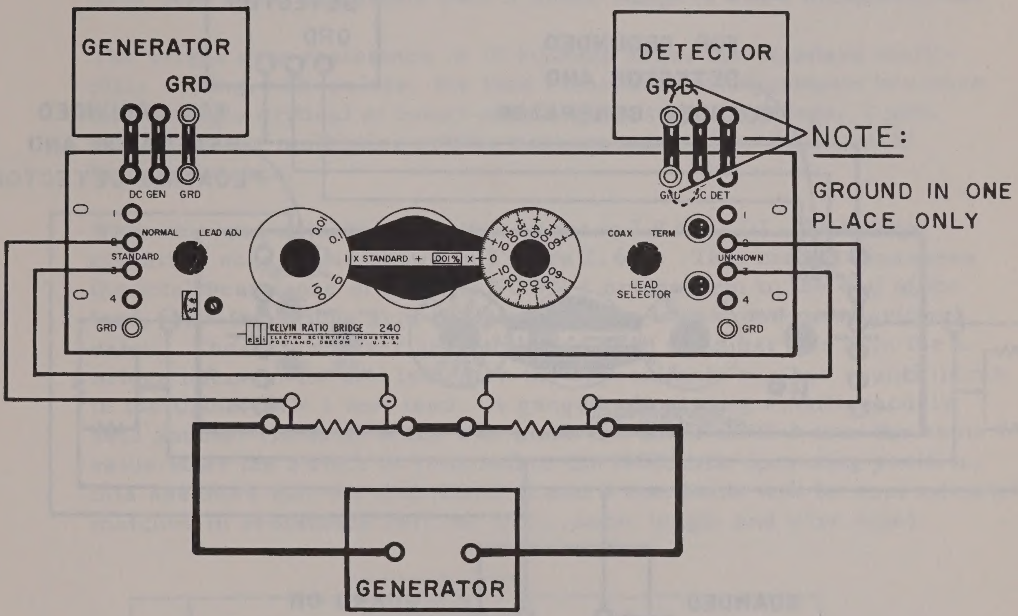


FIG. 2.5.3

2.5.4 CONNECTIONS FOR RESISTANCE MEASUREMENTS AT HIGH VOLTAGE

To measure high valued resistors at voltages high enough that they could cause break down in the bridge (1000 volts or more) or where it is desired to have equal voltage across the standard and unknown resistors instead of equal current, the connections shown in Fig. 2.5.4 should be used. (The connections shown are for three-terminal resistors.) It is necessary to have either a high-voltage power supply which is of completely guarded construction as described in Section 2.4.1 (the guarded terminal being the one connected to the junction of the unknown and standard) or a detector which can be isolated from ground as discussed in Sections 2.4.4 and 1.3.2.

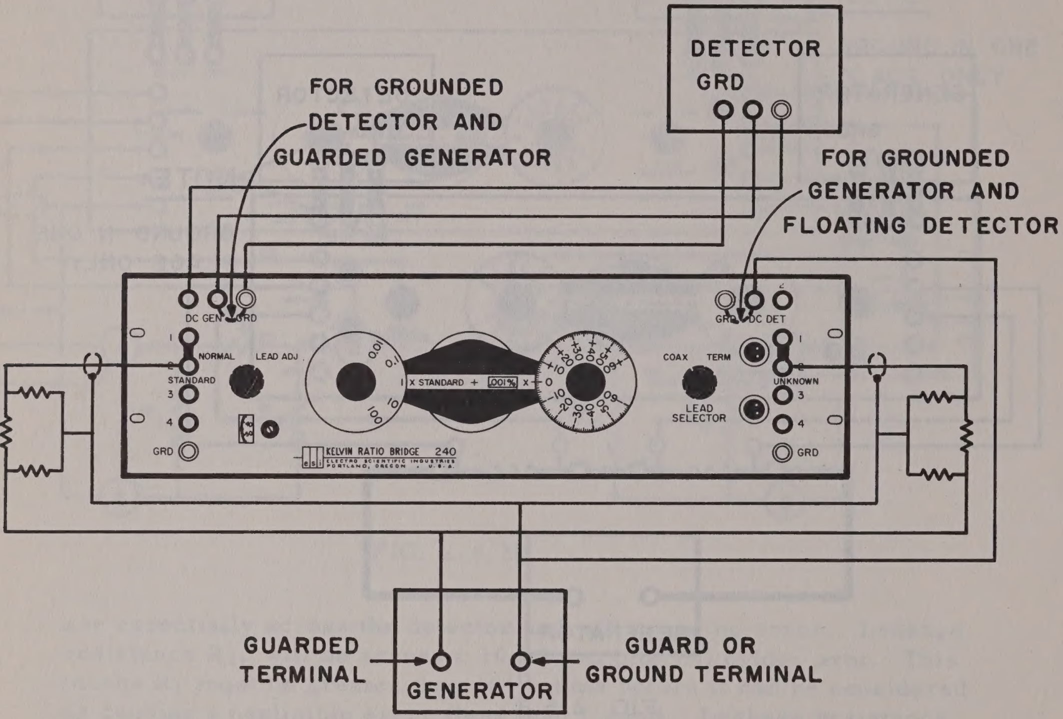


FIG. 2.5.4

2.6 LEAD RESISTANCE COMPENSATION ADJUSTMENT

2.6.1 GENERAL

When a four-terminal connection is made to the unknown resistor, the resistance of the test leads from UNKNOWN 2 and 3 appears in series with bridge arms of moderately high value, minimizing their effect. Since the effect is not always negligible, the bridge arms have been made adjustable over a small range to allow compensation.

The bridge arm resistance is 10 kilohms times the standard multiplier setting. Therefore, the lead compensation adjustment becomes increasingly critical at lower standard multiplier settings, 1 ppm divided by the multiplier setting corresponds to 10 milliohms of lead resistance.

When the lead adjustment switch is set to LEAD ADJ, the bridge circuit is changed as shown in Figure 2.6.1. This circuit measures the total resistance of the UNKNOWN 2 bridge arm to the end of its lead, with the bridge arm resistance at its lowest and most critical value. The screwdriver adjustment is used to adjust this arm for a bridge balance; its dial indicates the approximate number of milliohms in the UNKNOWN 2 test lead. A ganged adjustment simultaneously sets another rheostat which will make the UNKNOWN 3 arm the same value after the switch is returned to the NORMAL operating position; this assumes that the UNKNOWN 2 and 3 test leads will be approximately matched in resistance (will be of the same length and wire size).

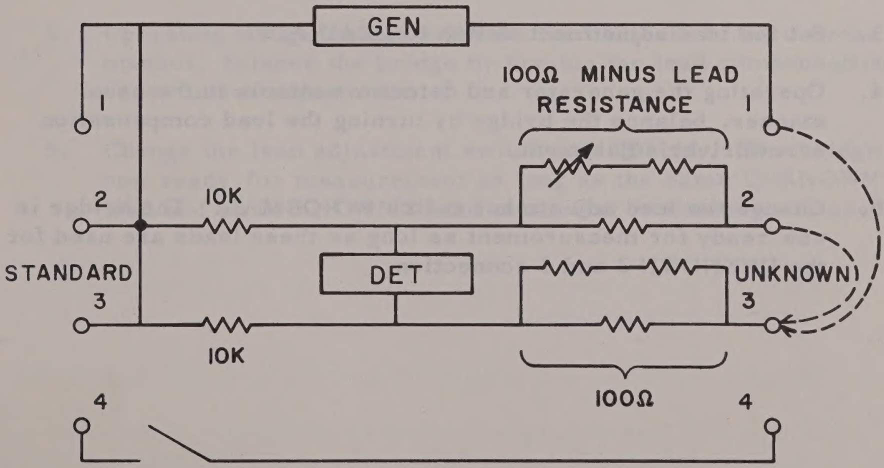


FIG. 2.6.1

2.6.2 LEAD ADJUSTMENT WITH KELVIN KLIP LEADS

The following adjustment compensates for the resistance of Kelvin Klip test leads. The adjustment will be correct both for use of the Kelvin Klip leads alone, and for use of the Kelvin Klip leads for the UNKNOWN 2 and 3 connections together with separate leads from UNKNOWN 1 and 4.

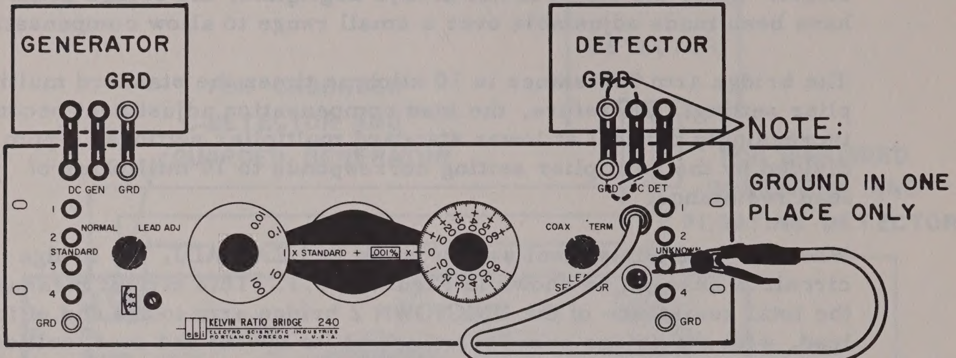


FIG. 2.6.2

1. Connect the Kelvin Klip from the upper lead to UNKNOWN 3, as shown in Fig. 2.6.2.
2. Set the lead selector to COAX.
3. Set the lead adjustment switch to LEAD ADJ.
4. Operating the generator and detector controls in the usual manner, balance the bridge by turning the lead compensation screwdriver adjustment.
5. Change the lead adjustment switch to NORMAL. The bridge is now ready for measurement as long as these leads are used for the UNKNOWN 2 and 3 connection.

2.6.3 LEAD ADJUSTMENT WITH FOUR SEPARATE LEADS

The following procedure compensates the bridge for the resistance of separate test leads connected to terminals UNKNOWN 2 and 3:

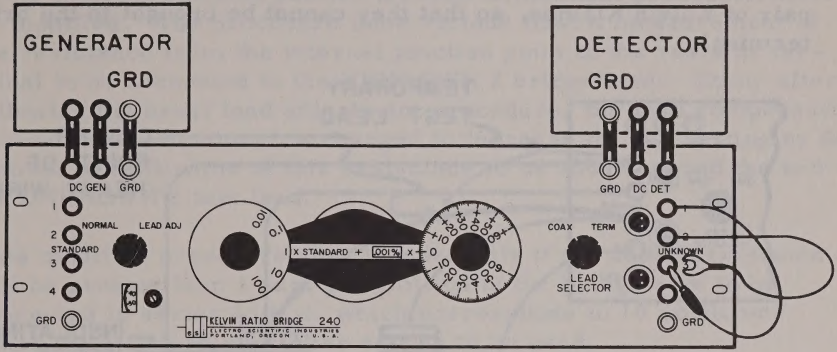


FIG. 2.6.3

1. Connect the outer ends of the UNKNOWN 1 and 2 leads to the UNKNOWN 3 terminal (one in the top and one in the side of the terminal), as shown in Fig. 2.6.3.

2. Set the lead selector to TERM.

3. Set the lead adjustment switch to LEAD ADJ.

4. Operating the generator and detector controls in the normal manner, balance the bridge by turning the lead compensation screwdriver adjustment.

5. Change the lead adjustment switch to NORMAL. The bridge is now ready for measurement as long as the same UNKNOWN 2 lead and an UNKNOWN 3 lead of similar resistance are used.

2.6.4 LEAD ADJUSTMENT WITH END OF LEAD AT A DISTANCE

The following procedure compensates the bridge for the resistance of test leads whose far ends are anchored to a test jig, such as a pair of Kelvin Klamps, so that they cannot be brought to the bridge terminals:

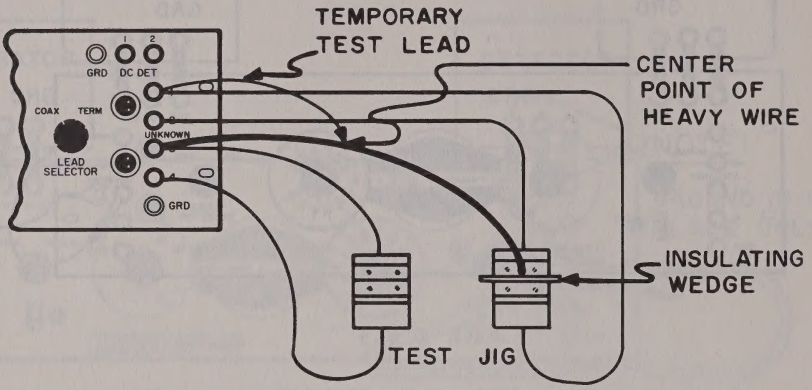


FIG. 2.6.4

1. Bring the end of the UNKNOWN 2 lead as close as practicable to the bridge, then connect its end to UNKNOWN 3 through a short, heavy piece of wire or bus bar, as shown in Fig. 2.6.4.
2. Connect a temporary test lead from the exact center of this heavy wire to UNKNOWN 1 (make sure the outer ends of the UNKNOWN 1 and 2 leads are not connected together for this adjustment).
3. Set the lead selector to TERM.
4. Set the lead adjustment switch to LEAD ADJ.
5. Operating the generator and detector controls in the normal manner, balance the bridge by turning the lead compensation screwdriver adjustment.
6. Remove the heavy wire and the temporary test lead to its center.
7. Change the lead adjustment switch to NORMAL. The bridge is now ready for measurement as long as the same UNKNOWN 2 lead and an UNKNOWN 3 lead of similar resistance are used.

2.6.5 COMPENSATION FOR LEAD RESISTANCE INSIDE A FOUR-TERMINAL RESISTOR

When the unknown to be measured is a four-terminal resistor of a construction having significant resistance from all of its terminals to the internal junction points, the lead adjustment procedure must be modified. The procedure must include first a measurement of the resistance from the internal junction point to the resistor terminal to be connected to the UNKNOWN 2 bridge lead. Then, after following the usual lead adjustment procedure, the lead compensation screwdriver adjustment is changed to increase its dial setting by the number of milliohms of this resistance to be added beyond the end of the UNKNOWN 2 test lead.

This modified procedure need be used only if the added resistance will be greater than 1 part per million of the bridge arm to be connected in series with it, which corresponds to 10 milliohms times the standard multiplier setting to be used.

The internal lead resistance in any four-terminal resistor can be measured by connecting it as shown in Fig. 2.6.5 and following the usual bridge operating procedure.

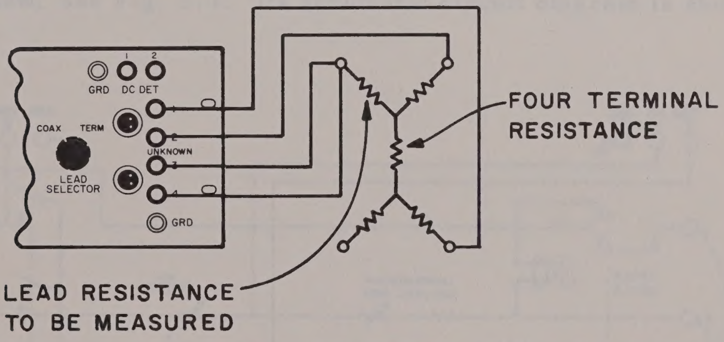


FIG. 2.6.5

SECTION III

THEORY OF OPERATION

3.1 GENERAL

The Kelvin double bridge was originally designed for accurately measuring very low-valued resistors. This is not possible with a Wheatstone bridge operated in the normal manner as a result of the uncertainty of the contact resistance to the resistor being measured. Measurements using the Wheatstone bridge can be improved by use of a four-terminal connection to the resistor under test, however, this places one of the connection resistances in series with a bridge arm which must also have a low value for maximum bridge sensitivity. With a Kelvin bridge two low-valued four-terminal bridge arms can be used, yet all connection resistances are made to appear in series with high resistance arms thus causing far less error.

The 240 is a modified Kelvin double bridge. The modifications include a five-range ratio multiplier, a lead resistance compensation adjustment, dials reading deviation from nominal ratio in percent or parts per million, and guarding to make the bridge suitable for high resistance measurements as well as low, see Fig. 3.1. Its schematic circuit diagram is shown in Fig. 5.3.2.

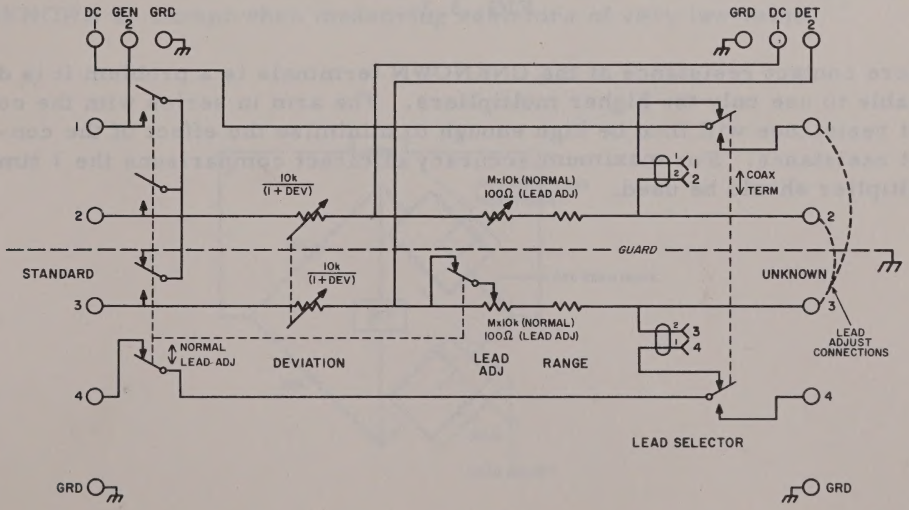


FIG. 3.1

3.2 STANDARD MULTIPLIER RATIOS

The STANDARD MULTIPLIER allows comparison of resistors in the ratios of 0.01:1, 0.1:1, 1:1, 10:1 and 100:1. This is accomplished by changing the ratio arms on the unknown side of the bridge from 100 ohms to 1 megohm while those on the standard side remain at 10 kilohms.

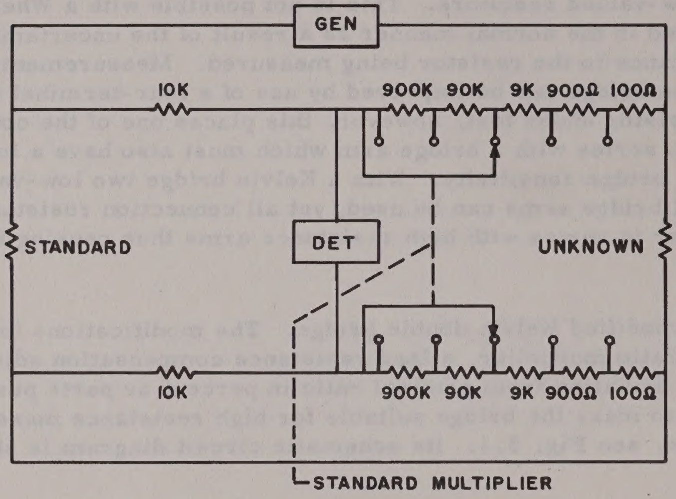


FIG. 3.2

Where contact resistance at the UNKNOWN terminals is a problem it is desirable to use only the higher multipliers. The arm in series with the contact resistance will then be high enough to minimize the effect of the contact resistance. For maximum accuracy of direct comparisons the 1 times multiplier should be used.

3.3 LEAD RESISTANCE COMPENSATION ADJUSTMENT

As more accurate measurements are sought, contact and lead resistances become more significant. Lead resistance is fairly stable and can be corrected or compensated for. In the 240 it is compensated for by adjusting the arm it is in series with. Contact resistance is not usually as stable. What must be done to minimize its effect is to make the contact resistances appear in series with high resistance arms thus swamping out their effect. On the one times range of the 240 the contact resistances will be in series with 10 kilohm bridge arms; on the 0.01 times range it is in series with only 100 ohms. Thus a contact resistance uncertainty of 10 milliohms will cause only a 1 ppm error on the 1 times range which can be neglected for most measurements but will cause a 100 ppm error on the 0.01 times range, which may not be negligible for certain measurements.

When the LEAD SELECTOR switch is in the LEAD ADJ position an internal Wheatstone bridge is formed to measure test lead resistance as shown in Fig. 3.3. One arm of this bridge consists of a variable resistance network in series with the test lead normally connected to terminal UNKNOWN 2; the other three arms are fixed. The lead compensation adjustment is then used to balance the bridge.

Ganged to the lead compensation adjustment is a similar variable resistance network which, in the normal operation of the bridge will be in series with the test lead connected to terminal UNKNOWN 3. It is therefore necessary that the two leads be approximately of equal resistance. The accuracy of the UNKNOWN 3 lead resistance compensation is much less critical than that of UNKNOWN 2, except when measuring resistors of very low value.

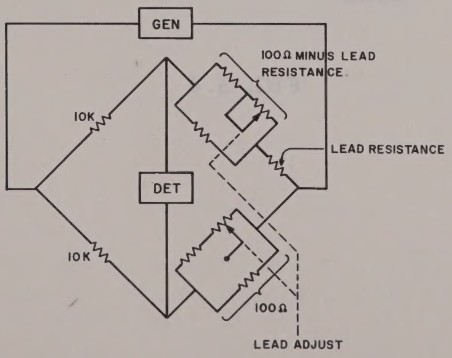


FIG. 3.3

3.4 DEVIATION DIALS

The deviation dials permit comparison between a fixed standard and an unknown resistor directly in percent or ppm deviation. This is accomplished with ganged rheostats varying the 10 kilohm arms on the standard side of the bridge. The conductance ($\frac{1}{R}$) varies from the 10 kilohm nominal value by the percent or ppm indicated on the deviation dials, producing a deviation from the nominal multiplier ratio of the same amount.

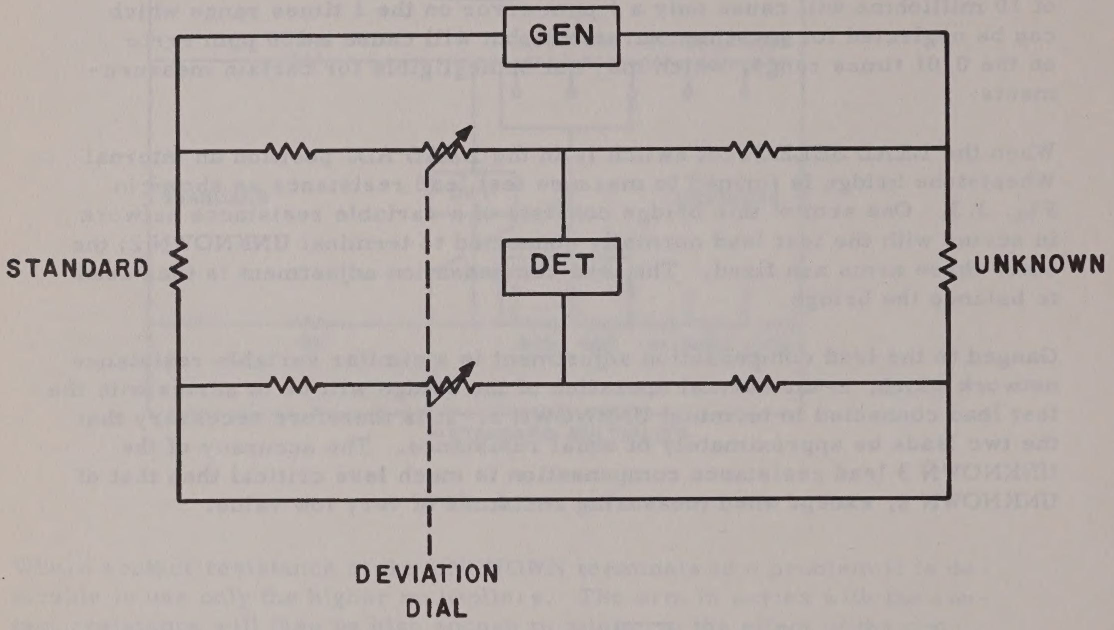


FIG. 3.4

3.5 GUARDING

In order to prevent internal leakage from appearing in shunt with the STANDARD or UNKNOWN terminals no switch deck or insulator is common to the upper two and the lower two STANDARD or UNKNOWN terminals. This allows the 240 to be used as a guarded bridge to measure very high valued resistors. To prevent external leakage from shunting the standard or unknown resistor three terminal connections should be used. See Section 2.5.2 GUARDED UNKNOWN AND STANDARD RESISTOR MEASUREMENTS.

3.6 ACCURACY ANALYSIS

Various factors affecting the accuracy of the main and auxiliary bridge ratios are discussed throughout this manual. The relative importance of main ratio accuracy versus auxiliary ratio accuracy depends upon the resistance of the "yoke" connection between the unknown and standard resistors (through terminal 4 of unknown and standard). The basic accuracy equation is:

$$d_{bridge} = d_m \left(1 + \frac{V_y}{V_s + V_x}\right) - d_a \left(\frac{V_y}{V_s + V_x}\right)$$

$$= d_m + (d_m - d_a) \left(\frac{V_y}{V_s + V_x}\right)$$

Where:

d_{bridge} is the resulting bridge ratio error
d_m is the main ratio error
d_a is the auxiliary ratio error
V_s is the standard resistor voltage (STANDARD 2 to STANDARD 3)
V_x is the unknown resistor voltage (UNKNOWN 2 to UNKNOWN 3)
V_y is the yoke voltage drop, including that inside the four-terminal standard and unknown resistors (STANDARD 3 to UNKNOWN 3)

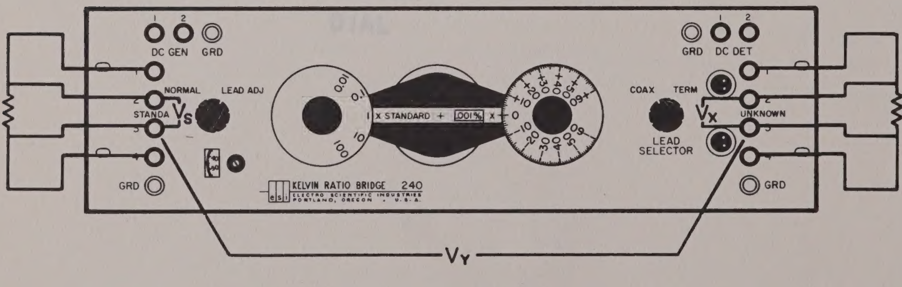


FIG. 3.6

It can be seen that the auxiliary ratio accuracy is relatively unimportant so long as the yoke voltage drop V_y is much smaller than the sum of the standard and unknown voltages $V_s + V_x$. When the yoke voltage is not negligible, it is important that the auxiliary ratio be accurately matched to the main ratio, so that $(d_m - d_a) = 0$. The effect of any error or change in adjustment in the main ratio will be magnified by the factor $(1 + \frac{V_y}{V_s + V_x})$ if the auxiliary ratio is not adjusted to match the main ratio.

The voltage ratio $\frac{V_y}{V_s + V_x}$ can either be calculated from measured voltages (Fig. 3.6) or estimated from the resistance ratio $\frac{R_y}{R_s + R_x}$. Each ratio error is the difference between the errors or deviations of the two resistors from their nominal values, in % or ppm (this is an approximation accurate to 1 ppm for resistors of 0.1% accuracy).

The manufacturing tolerance for the main ratio (d_m) is ±10 ppm on the 1 X STANDARD Multiplier and ±50 ppm on all others. The tolerance for the matching of the auxiliary ratio to the main ratio $(d_m - d_a)$ is ±50 ppm for the 0.01 X, 0.1 X and 1 X, ±500 ppm for the 10 X and ±5000 ppm for the 100 X STANDARD Multiplier. These tolerances do not take into account errors introduced by lead resistances.

SECTION IV

CALIBRATION

4.1 INTRODUCTION

This section provides MODEL 240 KELVIN RATIO BRIDGE calibration procedures for those that have the necessary facilities. Calibration should be performed in a laboratory environment. If this is not possible return the instrument to the factory or an authorized service facility for calibration.

The 240 is carefully tested and calibrated prior to shipment to insure that it conforms to published specifications. However, calibration should be performed periodically, always after repair or replacement of parts, for certification of traceability or when measurement accuracy better than that stated in the specifications is desired.

4.1.1 EQUIPMENT REQUIRED

1) 100 kilohm per step transfer standard: A series string of ten resistors with terminals brought out at each junction. Each resistor should be within ±0.005% of its nominal value with a short term drift of less than ±1 ppm. (ESI MODEL SR 1010 or equivalent).

2) Shorting bars: Paralleling straps for connecting ten resistors of the transfer standard in parallel and nine of the resistors in series-parallel. (ESI MODEL SB 103 or equivalent).

3) Decade resistor: 0 to 10 kilohms in 0.01 ohm steps, with an accuracy of ±(0.1% + 0.01 ohm) or better, a short term stability of at least 1 ppm, and each decade should go from 0 to ten. (ESI MODEL DB 62 or equivalent).

4) Decade resistor: 0 to 100 ohms in 0.1 ohm steps, with an accuracy of ±(0.1% + 0.01 ohm) or better, a short term stability of at least 1 ppm, and each decade should go from 0 to ten. (ESI MODEL DB 42 or equivalent).

5) Screwdriver: A small screwdriver for adjusting the test lead compensation rheostat.

4.2 INCREMENTAL ACCURACY

4.2.1 DEVIATION DIAL CALIBRATION

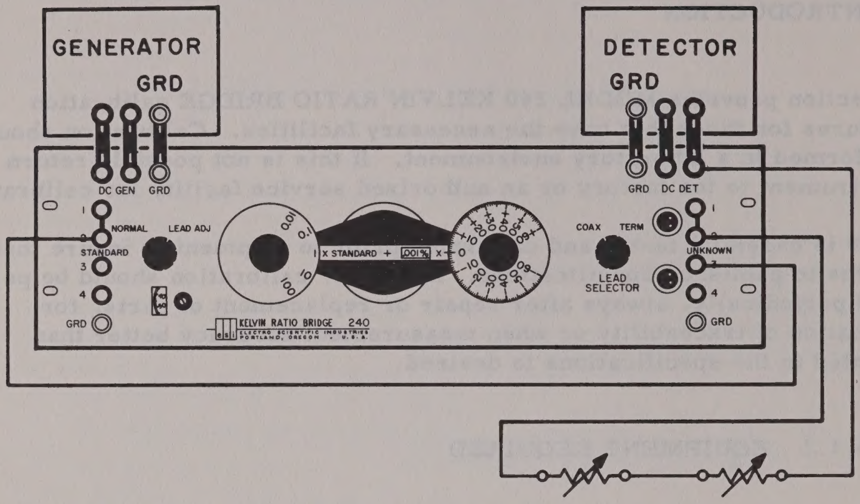


FIG. 4.2.1

1) Connect the generator and detector to the bridge. — See Section 2.4.

2) Set the Deviation Multiplier to 1 ppm.

3) Set the Deviation dial to 0.

4) Set the Standard Multiplier to 1 X.

5) Set the LEAD SELECTOR to TERM.

6) Set the LEAD ADJ switch to NORMAL.

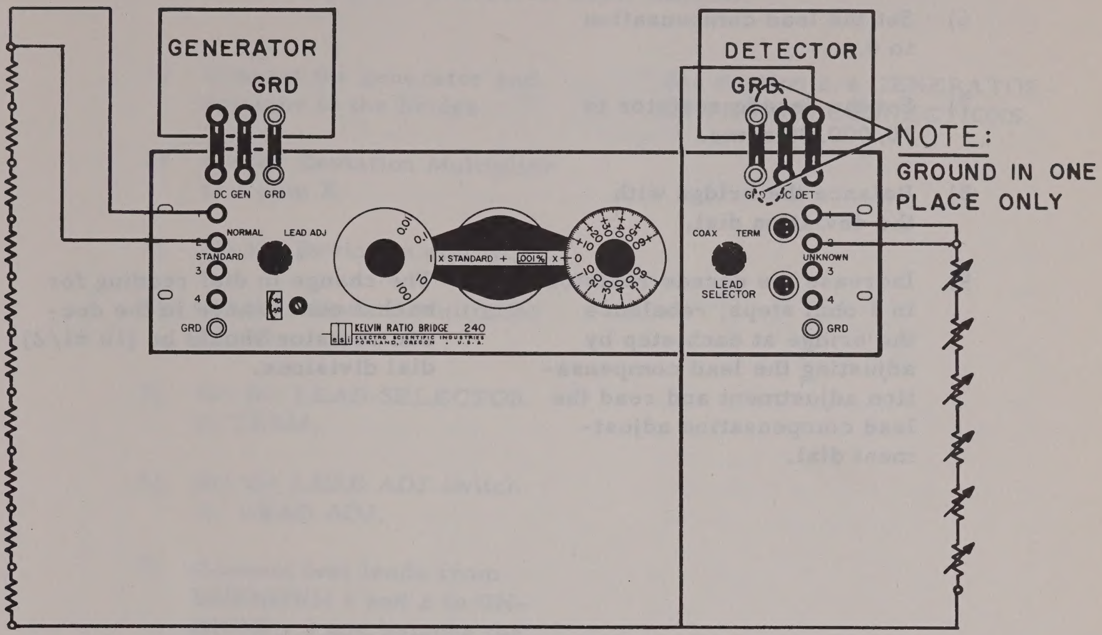
7) Connect bridge terminals UNKNOWN 3 and STANDARD 2 together. — Be sure good contact is made to both ends of the connecting lead.

8)	Connect the two decade resistance boxes in series and connect to terminals UNKNOWN 2 and DET 2 of the bridge.	See Section 4.1.1 EQUIPMENT REQUIREMENTS for recommended decade resistance boxes.
9)	Connect terminal STANDARD 1 to STANDARD 2 and UNKNOWN 1 to UNKNOWN 2.	There should be no connections made to terminals STANDARD 3 or 4.
10)	Set the 0.1 ohm per step decade resistor to 55.5 ohms and the 0.01 ohm per step decade resistor to approximately 9,944.50.	This will allow the deviation dial to be checked to ±50 divisions by changing only one decade of the 0.1Ω per step box on each deviation range.
11)	Turn the generator on and balance the bridge with the 0.01 ohm per step decade resistor leaving the 0.1 ohm per step decade resistor at 55.5 ohms.	Be sure the generator is limited to a maximum of 1 watt.
12)	Set the 0.1 ohm per step decade resistor to the values indicated in the table below. Balance the bridge with the Deviation dial at each indicated step.	The Deviation dial should be within 1 dial division of the value indicated in the right hand column.

DEV MULT	DECADE RES Setting in ohms	DEV DIAL Setting in dial div
1 ppm X	55.0	-50±1
	55.1	-40±1
	55.2	-30±1
	55.3	-20±1
	55.4	-10±1
	55.5	0
	55.6	+10±1
	55.7	+20±1
	55.8	+30±1
	55.9	+40±1
	55. TEN	+50±1

DEV MULT	DECADE RES Setting in ohms	DEV DIAL Setting in dial div
0.001% X	50.5	-50±1
	51.5	-40±1
	52.5	-30±1
	53.5	-20±1
	54.5	-10±1
	55.5	0±1
	56.5	+10±1
	57.5	+20±1
	58.5	+30±1
	59.5	+40±1
	5 TEN.5	+50±1
0.01% X	05.5	-50±1
	15.5	-40±1
	25.5	-30±1
	35.5	-20±1
	45.5	-10±1
	55.5	0±1
	65.5	+10±1
	75.5	+20±1
	85.5	+30±1
	95.5	+40±1
	TEN 5.5	+50±1

4.2.2 LEAD COMPENSATION ADJUSTMENT DIAL CALIBRATION



NOTE: GROUND IN ONE PLACE ONLY

Fig. 4.2.2

1) Connect the 0.01 ohm per step decade resistor and the series-connected 100K per step resistance transfer standard as shown in Fig. 4.2.2.

2) Set the Standard Multiplier to 0.01 X.

3) Set the Deviation Multiplier to 0.001% X.

4) Set the LEAD SELECTOR to TERM.

5) Set the LEAD ADJ switch to NORMAL.

6) Set the lead compensation to 0.

7) Set the decade resistor to 10,000.00 ohms.

8) Balance the bridge with the deviation dial.

9) Increase the decade resistor in 1 ohm steps; rebalance the bridge at each step by adjusting the lead compensation adjustment and read the lead compensation adjustment dial.

The change in dial reading for each 1 ohm change in the decade resistor should be (10 ±1/2) dial divisions.

4.3 MAIN RATIO CALIBRATION

4.3.1 1 X STANDARD MULTIPLIER RANGE

1) Connect the generator and detector to the bridge.

   See Section 2.4 GENERATOR-DETECTOR CONNECTIONS.

2) Set the Deviation Multiplier to 1 ppm X.

3) Set the Deviation dial to 0.

4) Set the Standard Multiplier to 1 X.

5) Set the LEAD SELECTOR to TERM.

6) Set the LEAD ADJ switch to LEAD ADJ.

7) Connect test leads from UNKNOWN 1 and 2 to UNKNOWN 3 and balance the bridge with the Lead Compensation adjustment.

8) Change the LEAD ADJ switch to NORMAL.

9) Connect ten resistors of the 100K per step transfer standard (item 1 of Section 4.1.1) in parallel, and connect this parallel combination together with the 0.01 ohm per step decade resistor (item 3 of Section 4.1.1) to the bridge as shown in Fig. 4.3.1.

   The resistance of the lead to STANDARD 2 should be kept less than 10 milliohms.

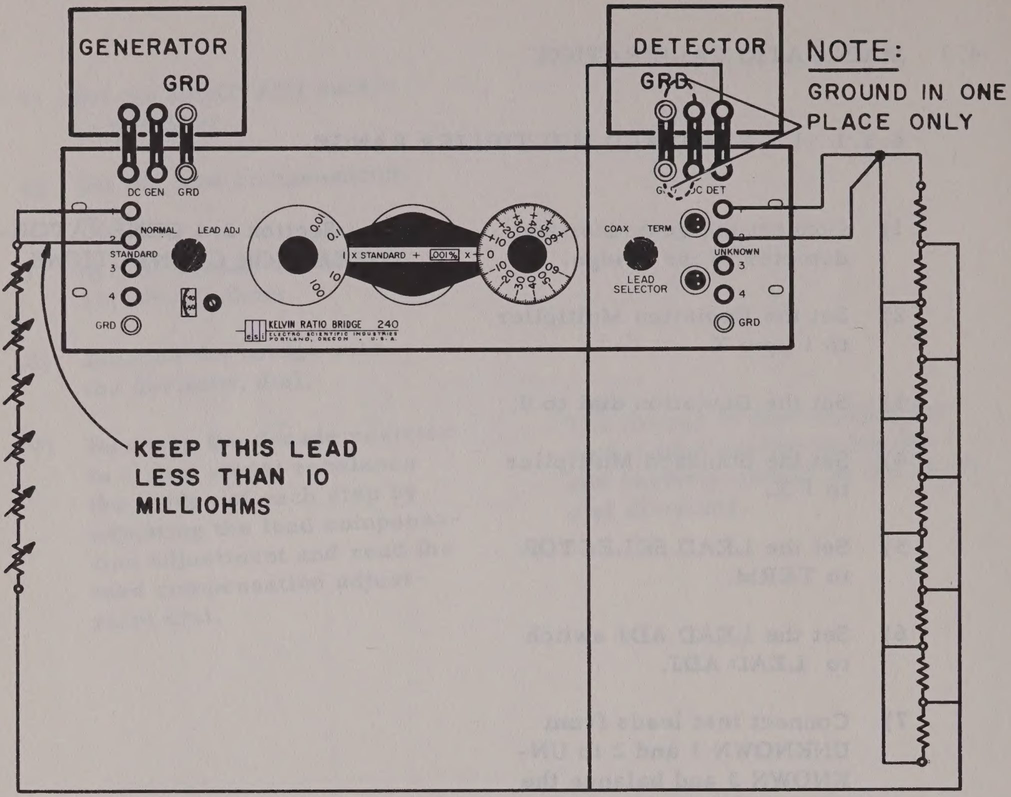


FIG. 4.3.1

10) Balance the bridge with the decade resistor.

11) Interchange the UNKNOWN 1 and 2 leads with the STANDARD 1 and 2 leads at the decade resistor and the transfer standard.

12) Rebalance the bridge with the Deviation dial.

It should balance with a resistance setting of about 10 kilohms on the decade resistor.

The transfer standard is now the standard and the decade resistor the unknown.

13)	Set the Deviation dial at one-half the reading obtained in step 12.	This deviation setting is the bridge error for the 1 X STANDARD and 1 ppm X deviation multiplier ranges; it should not exceed 10 dial divisions (10 ppm).
14)	Rebalance the bridge using the decade resistor.	This adjustment makes the decade resistor exactly equal to the resistance of the parallel combination.
15)	For better adjustment accuracy, set the deviation dial to 0 and rebalance the bridge by adjusting R_{11}.	See Fig. 5.3.1 for location of R_{11}.
16)	Change the Deviation Multiplier to 0.001% X and rebalance the bridge with the Deviation dial.	This deviation reading is the bridge error for the 1 X STANDARD and 0.001% X deviation multiplier ranges; it should not exceed 1 dial division (0.001%).
17)	For better adjustment accuracy, set the deviation dial at 0 and rebalance the bridge by adjusting R_8.	See Fig. 5.3.1 for location of R_8.
18)	Change the Deviation Multiplier to 0.01% X and rebalance the bridge with the Deviation dial.	This deviation reading is the bridge error for the 1 X STANDARD and 0.01% X deviation multiplier ranges; it should not exceed 1 dial division (0.01%).

4.3.2 100 X AND 0.01 X STANDARD MULTIPLIER RANGES

1)	Set the Standard Multiplier to 100 X and the deviation multiplier to 1 ppm X.	All other dial settings including those of the decade resistor remain as in Section 4.3.1.
2)	Remove the paralleling connection from the transfer standard and connect its ten resistors in series to the bridge as shown in Fig. 4.3.2.	The series connection of the transfer standard makes its resistance exactly 100 times that of the decade resistor.

3) Balance the bridge with the Deviation dial.

This Deviation dial reading is the error of the 100 X multiplier; it should be less than 50 ppm.

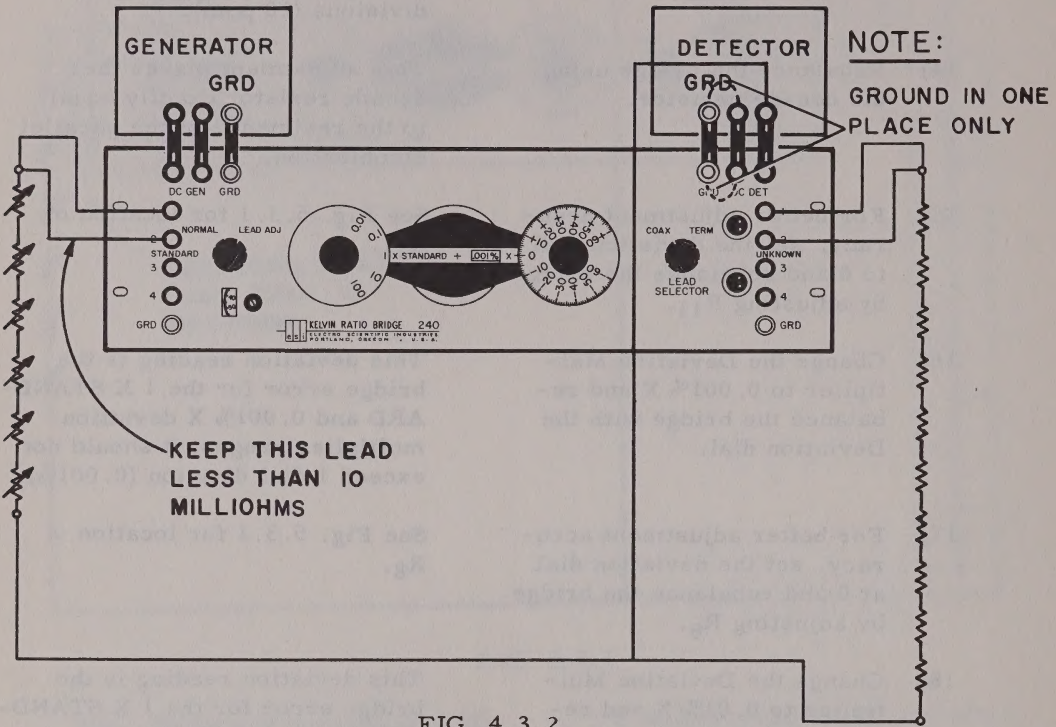


FIG. 4.3.2

4) Change the Standard Multiplier setting to 0.01 X.

5) Interchange the UNKNOWN 1 and 2 leads with the STANDARD 1 and 2 leads at the decade resistor and the transfer standard.

The transfer standard is now the standard and the decade resistor the unknown.

6) Balance the bridge with the Deviation dial.

This Deviation dial reading is the error of the 0.01 X multiplier and should be less than ±50 ppm.

4.3.3 10 X AND 0.1 X STANDARD MULTIPLIER RANGES

1) Set the Standard Multiplier at 10 X.

All other dial settings including those of the decade resistor remain as in Section 4.3.2.

2) Connect the first nine resistors of the transfer standard in series-parallel.

The series-parallel combination will have approximately 10 times the resistance of the decade resistor, and approximately the same value as any individual resistor in the transfer standard.

3) Connect the tenth resistor (the one not included in the series-parallel combination) and the decade resistor to the bridge as shown by the solid lines in Fig. 4.3.3.

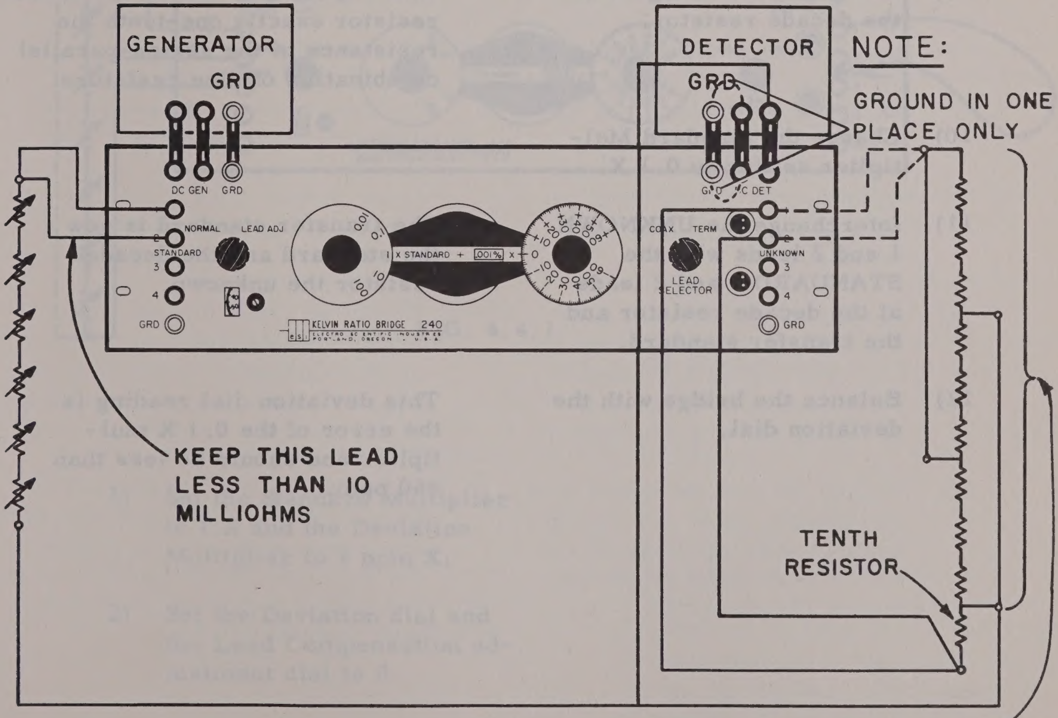


FIG. 4.3.3

4)	Balance the bridge with the deviation dial.	Call this reading D_1.
5)	Transfer the UNKNOWN 1 and 2 leads to the dotted connection shown in Fig. 4.4.3 to measure the series-parallel combination of nine resistors.	
6)	Balance the bridge with the deviation dial.	Call this reading D_2.
7)	Calculate $D_3 = 0.1D_1 + 0.9D_2$.	D_3 is the error of the 10 X multiplier and should be less than ±50 ppm.
8)	Set the deviation dial to D_3.	This adjustment makes the bridge ratio exactly 10:1.
9)	Rebalance the bridge with the decade resistor.	This adjustment makes the decade resistor exactly one-tenth the resistance of the series-parallel combination of nine resistors.
10)	Change the Standard Multiplier setting to 0.1 X.	
11)	Interchange the UNKNOWN 1 and 2 leads with the STANDARD 1 and 2 leads at the decade resistor and the transfer standard.	The transfer standard is now the standard and the decade resistor the unknown.
12)	Balance the bridge with the deviation dial.	This deviation dial reading is the error of the 0.1 X multiplier and should be less than ±50 ppm.

4.4 AUXILIARY RATIO CALIBRATION

4.4.1 RATIO MATCHING

The following tests check the accuracy with which the auxiliary ratio (between STANDARD 3 and UNKNOWN 3) is matched to the main ratio (between STANDARD 2 and UNKNOWN 2). The circuit of Fig. 4.4.1 is used to check the ratio matching accuracy on all Standrad Multiplier ranges, Deviation Multiplier ranges, Deviation dial settings and Lead Compensation adjustment settings.

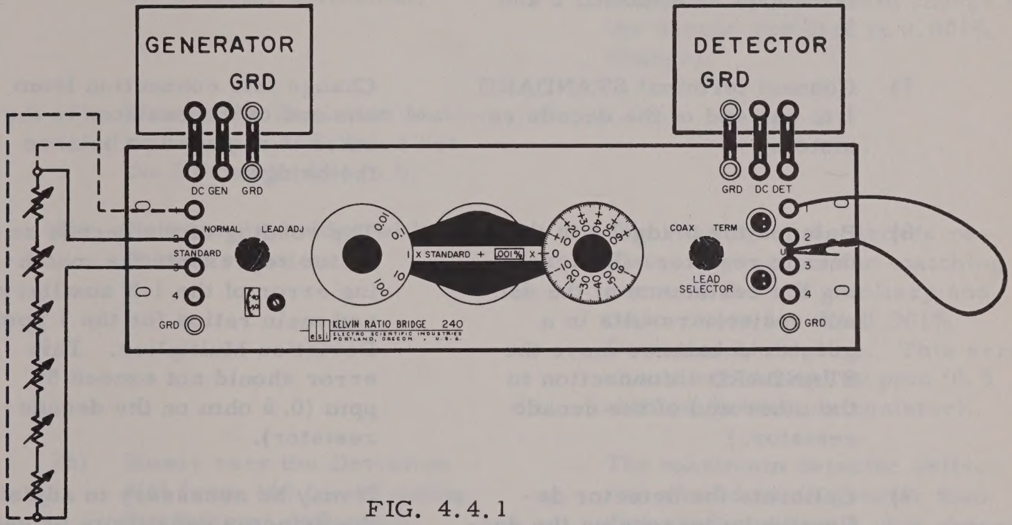


FIG. 4.4.1

1) Set the Standard Multiplier to 1 X and the Deviation Multiplier to 1 ppm X.

2) Set the Deviation dial and the Lead Compensation adjustment dial to 0.

3)	Set the LEAD ADJ switch to NORMAL.	
4)	Connect terminals UNKNOWN 2 and 3 together.	
5)	Connect UNKNOWN 1 to the center of the connecting link between UNKNOWN 2 and 3.	
6)	Connect the 0.01 ohm per step decade resistor, with all dials set to 0, between terminals STANDARD 2 and 3.	
7)	Connect terminal STANDARD 1 to one end of the decade resistor.	Change this connection from one end of the resistor to the other if required to balance the bridge.
8)	Balance the bridge with the decade resistor. (If increasing the resistance of the decade resistor results in a greater unbalance move the STANDARD 1 connection to the other end of the decade resistor.)	The reading of the decade resistor represents the matching error of the 1 X auxiliary and main ratios for the 1 ppm Deviation Multiplier. This error should not exceed 50 ppm (0.5 ohm on the decade resistor).
9)	Calibrate the detector deflection by increasing the decade resistor by 0.01 ohm (1 ppm change) and noting the resulting detector deflection.	It may be necessary to adjust the detector sensitivity or generator voltage to obtain a practical deflection; one that is about three fourths full scale.
10)	Return the decade resistor to the balance point and slowly vary the Deviation dial from +60 to -60 noting the deflection of the detector.	This checks the tracking of the auxiliary and main ratio deviation rheostats on the 1 ppm range. the detector should not deflect by more than the amount noted in step 9 above.

11)	Change the Deviation Multiplier to 0.001% X and set the Deviation dial to 0.	
12)	Balance the bridge with the decade resistor.	The reading of the decade resistor represents the matching error of the 1 X auxiliary and main ratios for the 0.001% Deviation Multiplier. This error should not exceed 50 ppm (0.5 ohm on the decade resistor).
13)	Slowly vary the Deviation dial from +60 to -60 noting the detector deflection.	The maximum detector deflection should be no greater than that produced by a 0.1 ohm change in the decade resistor (a 0.001% change).
14)	Change the Deviation Multiplier to 0.01% X and set the Deviation dial to 0.	
15)	Balance the bridge with the decade resistor.	The reading of the decade resistor represents the matching error of the 1 X auxiliary and main ratios for the 0.001% Deviation Multiplier. This error should not exceed 50 ppm (0.5 ohm on the decade resistor).
16)	Slowly vary the Deviation dial from +60 to -60 noting the detector deflection.	The maximum detector deflection should be no greater than that produced by a 1 ohm change in the decade resistor (a 0.01% change).
17)	Change the Deviation Multiplier to 1 ppm X and set the Deviation dial to 0.	
18)	Change the Standard Multiplier to 0.1 X and balance the bridge with the decade resistor.	The reading of the decade resistor represents the matching error of the 0.1 X auxiliary and main ratios for the 1 ppm Deviation Multiplier. This error should not exceed 50 ppm (0.5 ohm on the decade resistor).

19)	Change the Standard Multiplier to 0.01 X and balance the bridge with the decade resistor.	The reading of the decade resistor represents the matching error of the 0.01 X auxiliary and main ratios for the 1 ppm Deviation Multiplier. This error should not exceed 50 ppm (0.5 ohm on the decade resistor).
20)	Check the tracking of the lead compensation rheostats by slowly varying the Lead Compensation adjustment from 0 to maximum noting the detector deflection.	The maximum detector deflection should be no greater than that produced by a 0.2 ohm change in the decade resistor (a 2 milliohm change in the lead compensation rheostat).
21)	Reset the Lead Compensation adjustment to 0, change the LEAD ADJ switch to LEAD ADJ, and note the detector deflection.	This checks the matching of the lead adj circuit to the normal circuit. The maximum detector deflection should not be greater than that produced by a 0.1 ohm change in the decade resistor (a 1 milliohm change in the lead compensation).
22)	Return the LEAD ADJ switch to NORMAL.	
23)	Change the Standard Multiplier to 10 X and balance the bridge with the decade resistor.	The reading of the decade resistor represents the matching of the 10 X auxiliary and main ratios for the 1 ppm Deviation Multiplier. This error should not exceed 500 ppm (5 ohms on the decade resistor).
24)	Change the Standard Multiplier to 100 X and balance the bridge with the decade resistor.	The reading of the decade resistor represents the matching of the 100 X auxiliary and main ratios for the 1 ppm X Deviation Multiplier. This error should not exceed 5000 ppm (50 ohms on the decade resistor).

4.5 YOKE RESISTANCE

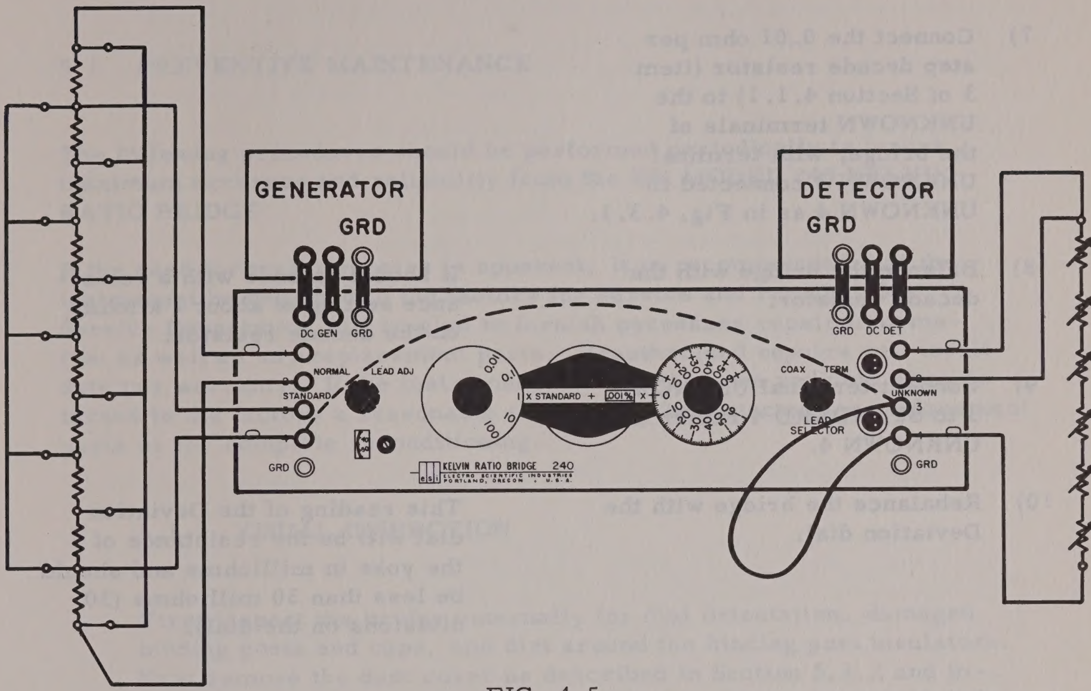


FIG. 4.5

1) Set the Standard Multiplier to 0.1 X.

2) Set the Deviation Multiplier to 1 ppm X.

3) Set the Deviation dial to 0.

4) Set the LEAD ADJ switch to NORMAL.

5) Set the LEAD SELECTOR to TERM.

6)	Connect 10 resistors to the transfer standard in parallel and connect to the STANDARD terminals of the bridge.	
7)	Connect the 0.01 ohm per step decade resistor (item 3 of Section 4.1.1) to the UNKNOWN terminals of the bridge, with terminal UNKNOWN 3 connected to UNKNOWN 4 as in Fig. 4.3.1.	
8)	Balance the bridge with the decade resistor.	It should balance with a resistance setting of about 1 kilohm on the decade resistor.
9)	Connect terminal UNKNOWN 3 to STANDARD 4 rather than UNKNOWN 4.	
10)	Rebalance the bridge with the Deviation dial.	This reading of the Deviation dial will be the resistance of the yoke in milliohms and should be less than 30 milliohms (30 divisions on the dial).

SECTION V

MAINTENANCE

5.1 PREVENTIVE MAINTENANCE

The following procedures should be performed periodically to insure maximum accuracy and reliability from the ESI MODEL 240 KELVIN RATIO BRIDGE.

If the need for major repairs is apparent, it is recommended that the instrument be returned to the factory for service and repair. Our Service Department will be glad to furnish necessary repair information as well as any replacement parts. Unauthorized repairs will invalidate our warranty. If the instrument is more than one year old when returned to the factory a reasonable charge may be expected for replacement parts or for complete reconditioning.

5.1.1 VISUAL INSPECTION

First inspect the bridge externally for dial orientation, damaged binding posts and caps, and dirt around the binding post insulators. Next remove the dust cover as described in Section 5.1.2 and inspect the unit for possible internal defects. These defects include such things as loose or broken connections, damaged switch contacts, worn potentiometers and sliders, and heat-damaged resistors.

5.1.2 REMOVING THE DUST COVER

Prepare a clean, smooth area to set the instrument. Be sure that no projections or pointed objects will be underneath the bridge panel. See that there are no metal filings in the area.

Remove the instrument from the rack and place it face down on the prepared surface.

Loosen the fasteners on the back of the instrument, then carefully slide the dust cover off.

5.1.3 CLEANING AND LUBRICATION

Clean the front panel with a soft, dry, lint free cloth being particularly careful to remove all dirt from around the binding post insulators. The only internal components which require cleaning and lubrication are the deviation rheostats and occasionally the switch decks.

Clean and lubricate the deviation rheostats as follows:

> Caution: Do not use solvents on the rheostats. Solvents may leave a residue which can affect their performance.

a) Polish the contact surfaces lightly with abrasive cloth (Crocus cloth or equivalent).

b) Remove loose particles by wiping with a Nylon cloth.

c) Apply a moderate amount of pure petroleum jelly to the contact surface.

The switch decks are carefully lubricated at the time of manufacture and are protected from contamination by the dust cover. They should rarely, if ever, need maintenance. It is recommended that they be cleaned and lubricated only if it is determined that they are not making good electrical contact. If it is determined that the switch decks are in need of cleaning proceed as follows:

a) Apply solvent (Freon printed circuit solvent or equivalent) to the contact surfaces with a small brush or pipe cleaner.

b) Wipe surface with clean dry brush or dry with low pressure air.

c) Apply a thin coating of lubricant (Oak #2008 or equivalent) to the contact surface.

d) Apply two drops of the same oil to each of the switch bearings and detent mechanisms.

e) Remove the excess oil with a clean dry cloth and remove all traces of lint with a soft brush.

5.1.4 CHECKING THE DIAL SETTINGS

In order to check that the dials are in their proper positions with respect to the shafts, the following procedure can be used:

Turn the STANDARD MULTIPLIER DIAL clockwise until a stopped position is reached. The dial should then read 0.01X.

Turn the DEVIATION MULTIPLIER DIAL clockwise until a stopped position is reached. The dial should then read 0.01%X.

Turn the DEVIATION DIAL clockwise until the end point is felt. The dial should read -60. Turn the dial counter clockwise until the end point is felt. The dial should read +60.

5.1.5 REPLACING THE DUST COVER

Be sure that the interior of the dust cover is completely clear of all foreign material.

Slip the dust cover over the bridge being careful not to touch the dust cover against the bridge resistors. Replace the dust cover screws.

Replace the assembled instrument in the rack.

5.2 TROUBLE SHOOTING

The following table lists various abnormal indications, probable cause and corrective procedures for the MODEL 240 KELVIN RATIO BRIDGE. Troubles may be located quickly by first performing a basic measurement (Section II) to aid in locating the trouble, then refer to the following table and component location illustrations. Calibrate the instrument after any repair or replacement is performed. (See Section IV, CALIBRATION for recommended procedures.)

5.2.1 TROUBLE SHOOTING CHART

SYMPTOM	PROBABLE CAUSE	PROCEDURE
Deviation dial setting affects balances on Lead Compensation.	Deviation potentiometers not aligned properly.	Turn the deviation dial counter clockwise to the +60 position. Check that the arms of both potentiometers are then hitting their stops.
Adjusting the deviation dial causes erratic detector readings.	Dirty deviation potentiometers.	Polish the contact surface lightly with Crocus cloth, remove the loose particles by wiping with a Nylon cloth and then lubricate liberally with pure petroleum jelly.
No detector deflection, apparent loss of generator voltage.	Bad connection to the terminal STANDARD 1 or UNKNOWN 1.	Check all contacts to be sure they are tight and contact surfaces are clean. Check all leads for continuity.
Detector indicates extreme bridge unbalance.	Bad connection to the STANDARD or UNKNOWN terminals.	Check all contacts to be sure they are tight and contact surfaces are clean. Check all leads for continuity.

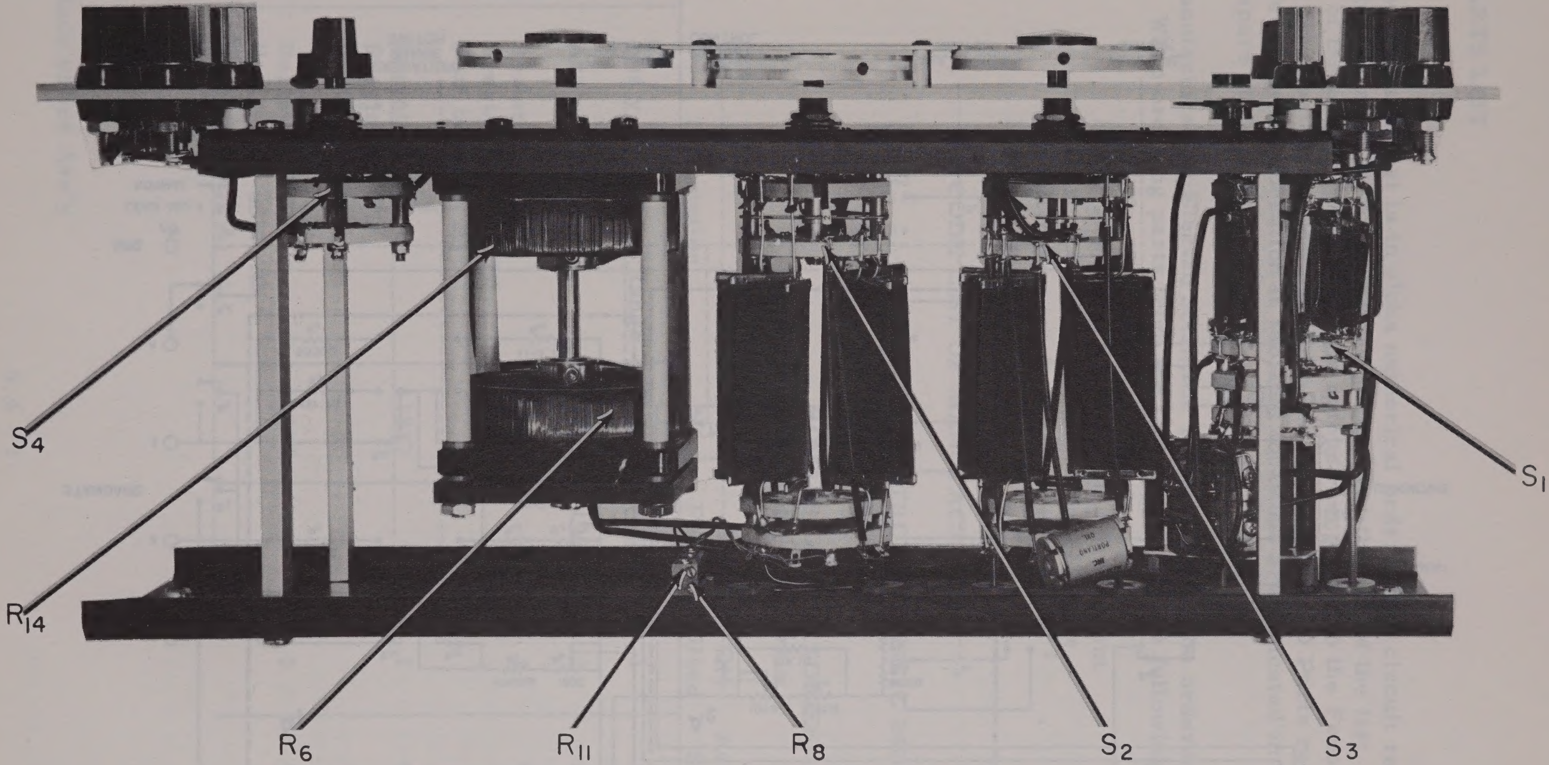
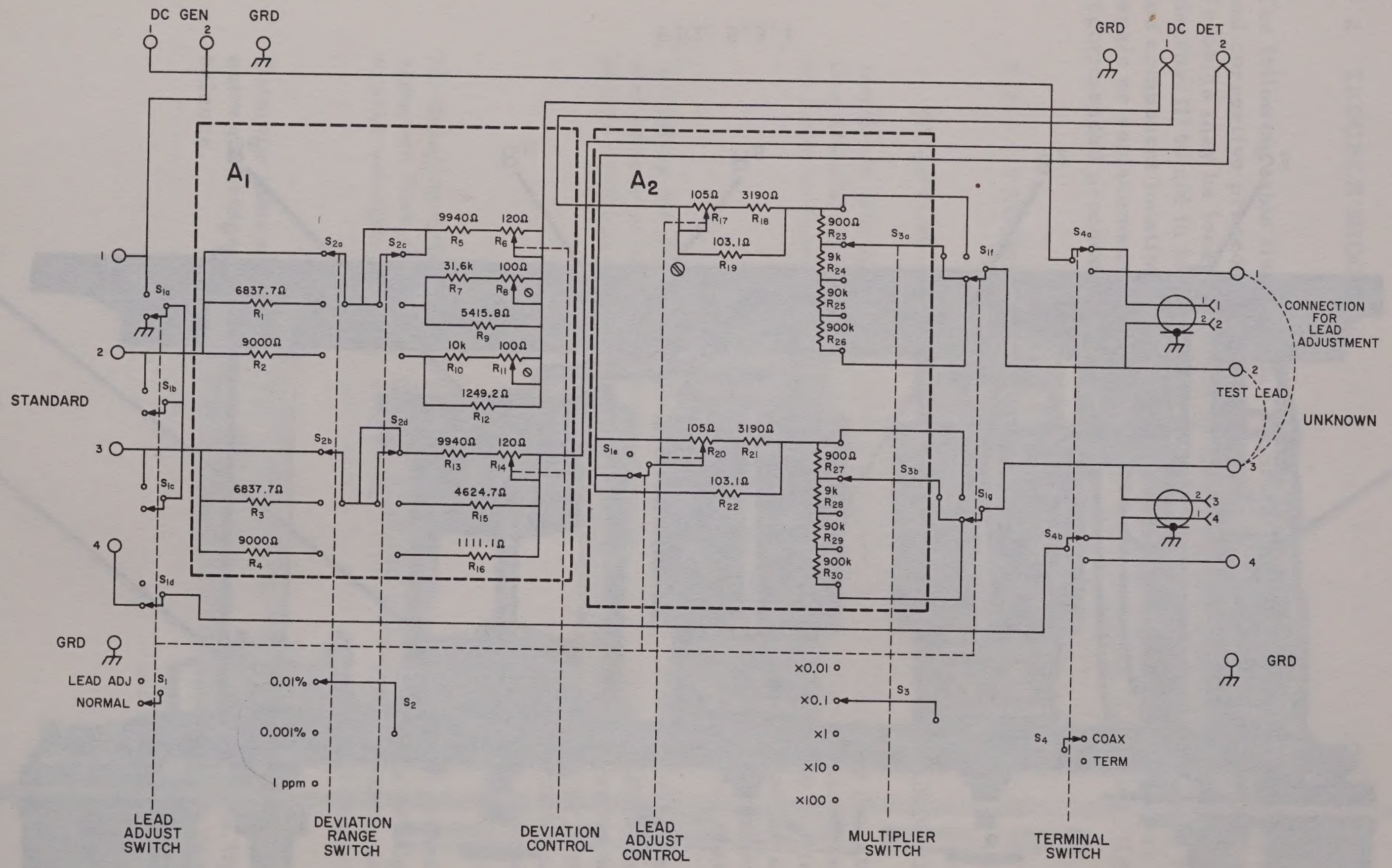


FIG. 5.3.1



esi MODEL 240 CIRCUIT DIAGRAM

FIG. 5.3.2

5.4 PARTS LIST

The following parts list is in alpha numerical order of the circuit reference designator. Miscellaneous parts are included at the end of the list. Manufacturer of the part is given in a code number according to the Federal Supply Code for Manufacturers; see list of manufacturers below. Parts recommended as spares to sustain operation in isolated locations are indicated in the recommended spare parts column.

Parts manufactured by Electro Scientific Industries must be ordered from the factory. When ordering parts from the factory include the following information:

Model and serial number of the instrument
Electro Scientific Industries part number
Circuit reference designator
Description of part

CODE LIST OF MANUFACTURERS

11837	ELECTRO SCIENTIFIC INDUSTRIES Portland, Oregon
80294	BOURNS LABORATORIES, INC. Riverside, California

Ckt Ref	Description	Mfr.	ESI Part No.	Qty Used	Recm SP
A_1	Ass'y, Deviation Range	11837	9537	1	1
A_2	Ass'y, Multiplier	11837	9536	1	1
R_1	Resistor, Fixed, Precision, 6837.7Ω, Part of Ass'y A_1	11837	*	1	*
R_2	Resistor, Fixed, Precision, 9K, Part of Ass'y A_1	11837	*	1	*
R_3	Resistor, Fixed, Precision, 6837.7Ω, Part of Ass'y A_1	11837	*	1	*

* Replace entire Ass'y

Ckt Ref	Description	Mfr.	ESI Part No.	Qty Used	Recm SP
R_4	Resistor, Fixed, Precision, 9K, Part of Ass'y A_1	11837	*	1	*
R_5	Resistor, Fixed, Precision, 9940Ω, Part of Ass'y A_1	11837	*	1	*
R_6	Resistor, Variable, 120Ω, Part of Ass'y A_1	11837	*	1	*
R_7	Resistor, Fixed, Precision, 31.6K, Part of Ass'y A_1	11837	*	1	*
R_8	Resistor, Variable, wire wound, 100Ω, Mfg. PN Trimpot 224L-1-101, Part of Ass'y A_1	80294	8464	1	*
R_9	Resistor, Fixed, Precision, 5115.8Ω, Part of Ass'y A_1	11837	*	1	*
R_{10}	Resistor, Fixed, Precision, 10K, Part of Ass'y A_1	11837	*	1	*
R_{11}	Resistor, Variable, wire wound, 100Ω, Mfg. PN Trimpot 224L-1-101, Part of Ass'y A_1	80294	8464	1	*
R_{12}	Resistor, Fixed, Precision, 1249.2Ω, Part of Ass'y A_1	11837	*	1	*
R_{13}	Resistor, Fixed, Precision, 9940Ω, Part of Ass'y A_1	11837	*	1	*

* Replace entire Ass'y

Ckt Ref	Description	Mfr.	ESI Part No.	Qty Used	Recm SP
R_{14}	Resistor, Variable, 120Ω, Part of Ass'y A_1	11837	*	1	*
R_{15}	Resistor, Fixed, Precision, 4624.7Ω, Part of Ass'y A_1	11837	*	1	*
R_{16}	Resistor, Fixed, Precision, 1111.1Ω, Part of Ass'y A_1	11837	*	1	*
R_{17}	Resistor, Variable, 105Ω, Part of Ass'y A_2	11837	*	1	*
R_{18}	Resistor, Fixed, Precision, 3190Ω, Part of Ass'y A_2	11837	*	1	*
R_{19}	Resistor, Fixed, Precision, 103.1Ω, Part of Ass'y A_2	11837	*	1	*
R_{20}	Resistor, Variable, 105Ω, Part of Ass'y A_2	11837	*	1	*
R_{21}	Resistor, Fixed, Precision, 3190Ω, Part of Ass'y A_2	11837	*	1	*
R_{22}	Resistor, Fixed, Precision, 103.1Ω, Part of Ass'y A_2	11837	*	1	*
R_{23}	Resistor, Fixed, Precision, 900Ω, Part of Ass'y A_2	11837	*	1	*
R_{24}	Resistor, Fixed, Precision, 9K, Part of Ass'y A_2	11837	*	1	*

* Replace entire Ass'y

Ckt Ref	Description	Mfr.	ESI Part No.	Qty Used	Recm SP
R_{25}	Resistor, Fixed, Precision, 90K, Part of Ass'y A_2	11837	*	1	*
R_{26}	Resistor, Fixed, Precision, 900K, Part of Ass'y A_2	11837	*	1	*
R_{27}	Resistor, Fixed, Precision, 900Ω, Part of Ass'y A_2	11837	*	1	*
R_{28}	Resistor, Fixed, Precision, 9K, Part of Ass'y A_2	11837	*	1	*
R_{29}	Resistor, Fixed, Precision, 90K, Part of Ass'y A_2	11837	*	1	*
R_{30}	Resistor, Fixed, Precision, 900K, Part of Ass'y A_2	11837	*	1	*
S_1	Switch, Rotary, Lead Adjust	11837	8342	1	1
S_2	Switch, Rotary, Range, Deviation, Part of Ass'y A_1	11837	*	1	*
S_3	Switch, Rotary, Multiplier, Part of Ass'y A_2	11837	*	1	*
S_4	Switch, Rotary, Lead Selector	11837	8323	1	1

* Replace entire Ass'y

Ckt Ref	Description	Mfr.	ESI Part No.	Qty Used	Recm SP
	MISCELLANEOUS				
	Cover, Dust	11837	3246	1	
	KELVIN KLIP Ass'y	11837	8309	2	2
	Connector	11837	8307	2	1
	Insulator, Switch Stacking Bolt	11837	2326	6	2
	Insulator, Binding Post, Rear	11837	8823	12	
	Window, Lead Adj	11837	8368	1	
	Post, Binding	11837	1393	16	
	Bushing, Deviation Dial	11837	2799	1	
	Cap, Binding Post, Metal	11837	1172	4	2
	Cap, Binding Post, Ins.	11837	1170	12	5
	Knob	11837	1270	2	
	Dial, Lead Adjust	11837	8361	1	
	Dial, Std. Multiplier	11837	8375	1	
	Dial, Deviation Multiplier	11837	8372	1	
	Dial, Deviation	11837	8370	1	
	Index, Lead Adj	11837	8360	1	
	Mask, Deviation Multiplier Dial	11837	8377	1	

Electro Scientific Industries
7524 S. W. MACADAM AVE. • PORTLAND 19, OREGON

**BRIDGES
AND
ACCESSORIES**

AUGUST 1963

MODEL

RS 925

Instruction Manual

RESISTANCE
STANDARD

T.O. 33-A1-12-451-1

RESISTANCE STANDARD RS 925
ELECTRO SCIENTIFIC INDUSTRIES
PORTLAND, OREGON • U.S.A.
OHMS
GRD

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LITHO IN U.S.A.

TABLE OF CONTENTS

I. DESCRIPTION AND SPECIFICATIONS

- 1.1 DESCRIPTION
- 1.2 SPECIFICATIONS

II. OPERATING INSTRUCTIONS

- 2.1 RESISTANCE SELECTION KNOBS
- 2.2 RESISTANCE TERMINALS
- 2.3 FOUR-TERMINAL APPLICATIONS
- 2.4 POWER LIMITATIONS

III. PREVENTIVE MAINTENANCE

- 3.1 VISUAL INSPECTION
- 3.2 REMOVING THE DUST COVER
- 3.3 CLEANING AND LUBRICATION
- 3.4 REPLACING THE DUST COVER

IV. PARTS LIST

SECTION I

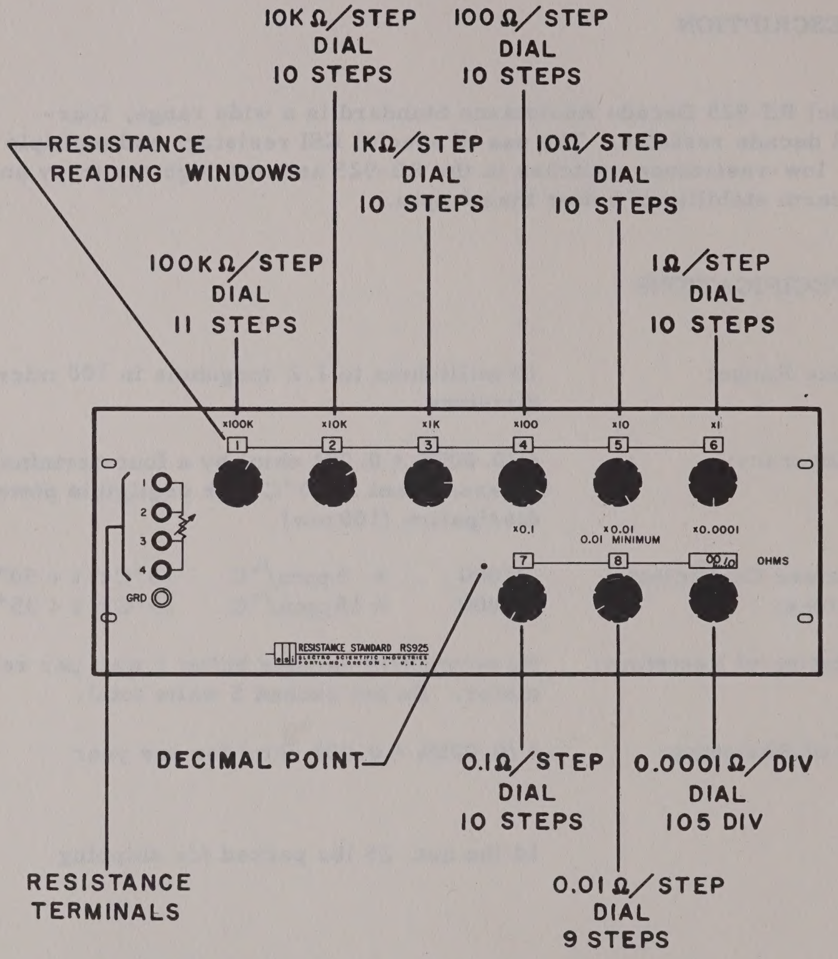
DESCRIPTION AND SPECIFICATIONS

1.1 DESCRIPTION

The Model RS-925 Decade Resistance Standard is a wide range, four-terminal decade resistor. The use of special ESI resistors and multiple contact, low-resistance switches in the RS-925 assures high accuracy and a short term stability of better than 1 ppm.

1.2 SPECIFICATIONS

Resistance Range:	10 milliohms to 1.2 megohms in 100 microhm divisions
Initial Accuracy:	± (0.005% + 0.002 ohm) by a four-terminal measurement at 25°C with negligible power dissipation (100 mw)
Temperature Coefficient of Resistors:	≥100Ω ± 5 ppm/°C 10°C < t < 50°C <100Ω ± 15 ppm/°C 15°C < t < 35°C
Power Rating of Resistors:	No permanent damage below 1 watt per resistor. Do not exceed 5 watts total.
Stability of Resistors:	± (0.005% + 0.001 ohm) for one year
Weight:	14 lbs net, 25 lbs packed for shipping



MODEL RS925 PANEL CONTROLS

SECTION II

OPERATING INSTRUCTIONS

2.1 RESISTANCE SELECTION KNOBS

The first knob on the left in the top row is used to change the four-terminal resistance in steps of 100 kilohms. The successive seven knobs are used to adjust the resistance in units down to 10 milliohms. The last knob in the bottom row varies a 10.5 milliohm potentiometer which is connected as a four-terminal variable resistor. The dial reading in the window above each knob is an in-line resistance reading.

Engraved above each window is the resistance per step of that decade. A decimal point is engraved on the panel to the left of the 0.1 ohm per step decade.

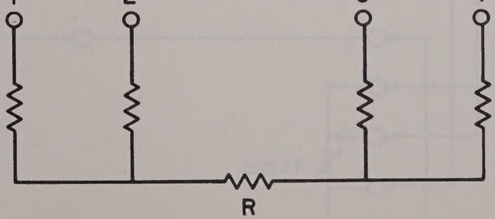
The minimum reading on the 0.01 ohm per step decade is 0.01 ohm since this is the minimum internal resistance of the RS-925. An effective zero reading may be obtained on the 0.01 ohm per step dial by reducing the setting of the 0.1 ohm per step dial one position and setting the 0.01 ohm per step dial at (TEN).

2.2 RESISTANCE TERMINALS

The terminals provided permit four-terminal connection to an external circuit. The ground terminal is provided for convenience.

2.3 FOUR-TERMINAL APPLICATIONS

The ESI Model RS-925 is constructed with four terminals as shown below.



If current is passed from one of the four terminals to a terminal at the opposite end of the resistor R, and the voltage is measured between the remaining two terminals, the four-terminal resistance of R is the ratio of the measured voltage to the current. Four terminal resistors are normally used for meter shunt applications and as resistance standards for Kelvin bridge measurements.

a) Meter Shunt Applications

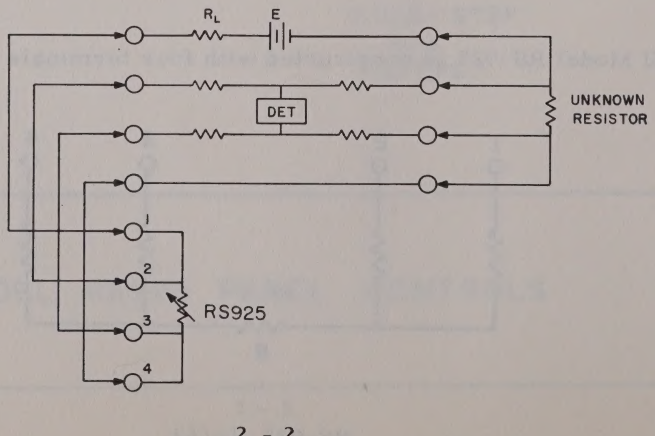
To measure the current in a four-terminal resistance, the voltage drop is measured between the two-terminals of the resistor not connected to the source. The current is then determined by the ratio of the measured voltage to the known resistance. Use of the four-terminal technique avoids measuring errors caused by voltage drops in the current carrying leads and contacts. Errors caused by lead and contact resistance in the voltage measuring circuit are negligible if the current in this circuit is small.

b) Kelvin Bridge Applications

A four-terminal resistance standard is used for all Kelvin bridge measurements. Errors caused by lead and contact resistances are usually negligible because they appear as part of the generator or yoke resistance, or in series with high resistance bridge arms.

For optimum performance with a Kelvin bridge connect the RS-925 terminals as follows:

1. Generator
2. Bridge (generator side)
3. Bridge (yoke side)
4. Yoke



2.4 POWER LIMITATIONS

For maximum protection and accuracy it is recommended that the available power to the RS-925 Resistance Standard be limited to ONE WATT. This is accomplished by placing a resistor in series with the bridge generator or battery.

The value of this resistance can be calculated from the following formula:

$$R_L = \frac{E^2}{4}$$

where

R_L is the value of the power limiting resistor.

E is the open circuit voltage of the generator.

The protective resistor should have a power rating of 4 watts or more. Input power should be limited to 1/10 watt or less for most accurate measurements.

SECTION III

PREVENTIVE MAINTENANCE

The following procedures should be performed periodically (approximately once a year) to insure maximum accuracy and reliability from the ESI MODEL RS-925 RESISTANCE STANDARD.

If the need for major repairs is apparent, it is recommended that the unit be sent to the factory for service. The service department will be glad to furnish the necessary information for repairs as well as any replacement parts. However, unauthorized repairs will invalidate the instrument warranty. If the instrument is more than one year old when returned to the factory, a reasonable charge may be expected for replacement of parts or complete reconditioning.

3.1 VISUAL INSPECTION

Inspect the bridge for dial orientation and damage to binding posts and binding post caps. Also check for dirt around the binding post insulators. Then remove the dust cover as described in Section 3.2 and inspect the unit for possible internal defects. These defects include such things as loose or broken connections, damaged or dirty switch contacts, worn or dirty potentiometers and sliders, and heat damaged resistors.

3.2 REMOVING THE DUST COVER

Prepare a soft, clean place to set the instrument. Be sure that no projections or pointed objects will be underneath the panel. See that there are no metal fillings in the area.

Remove the instrument from the rack and place it face down on the prepared surface. Loosen the screws on the back of the instrument and carefully slide the dust cover off.

3.3 CLEANING AND LUBRICATION

Clean the front panel with a soft, dry, lint-free cloth, being particularly careful to remove all dirt from around the binding post insulators. The only internal component which requires cleaning and lubrication is the potentiometer, and occasionally the switch decks. Clean and lubricate the potentiometer as follows:

> CAUTION: Do not use solvents on the potentiometer. Solvents will leave a residue which may affect their performance.

a) Polish the contact surface lightly with an abrasive cloth (Crocus cloth or equivalent).

b) Remove loose particles by wiping with a nylon cloth.

c) Apply a moderate amount of pure petroleum jelly to the contact surface.

The switch decks are carefully lubricated at the time of manufacture and are protected from contamination by the dust cover. They should rarely, if ever, require maintenance. It is recommended that they be cleaned or lubricated only if it is determined that they are not making good electrical contact. If the switch decks are in need of cleaning or lubrication, proceed as follows:

a) Apply solvent (Freon printed circuit solvent or equivalent) to the contact surfaces with a small brush or pipe cleaner.

b) Wipe surfaces with clean, dry brush or dry with low pressure air.

c) Apply a thin coating of lubricant (Oak #2008 or equivalent) to the contact surfaces with a hypodermic needle.

d) Apply two drops of the same oil to each of the switch bearings and detent mechanisms.

e) Remove excess oil with a clean, dry cloth and remove all traces of lint with a soft brush.

3.4 REPLACING THE DUST COVER

Be sure that the interior of the dust cover is completely clear of all foreign material.

Slip the dust cover over the bridge being careful not to touch any resistors with the cover. Replace the screws.

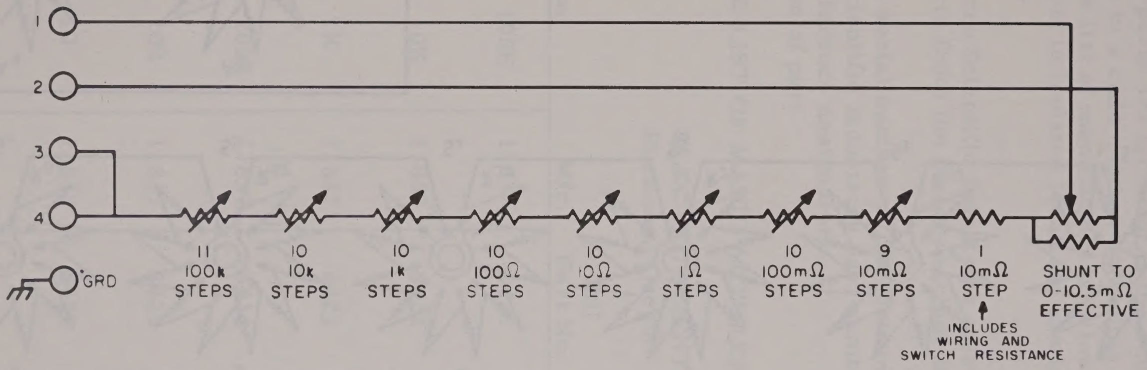
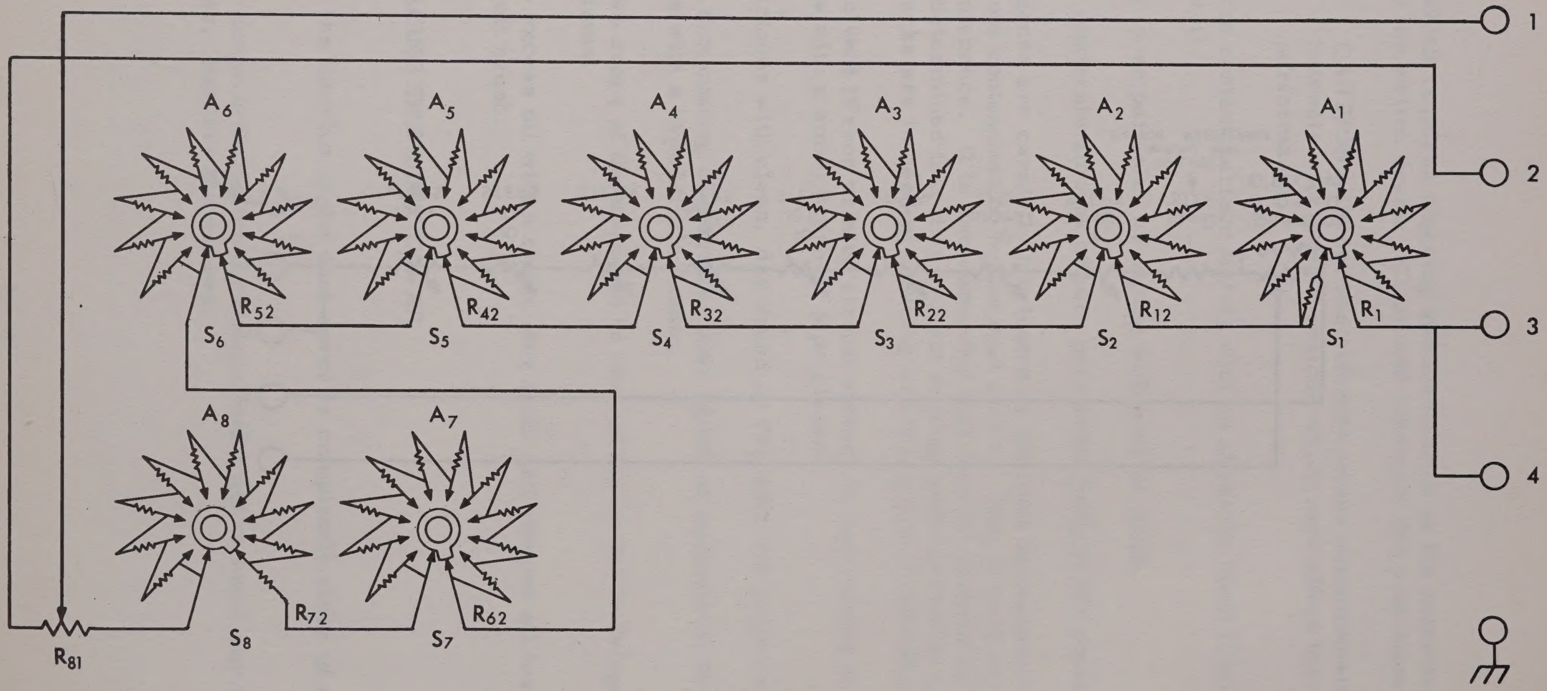


Fig. 3.1 RS-925 CIRCUIT DIAGRAM



RS 925

WIRING DIAGRAM

Fig. 3.2

PARTS LIST

The following parts list is in alpha numerical order of the circuit reference designator. Miscellaneous parts are included at the end of the list. Manufacturer of the part is given in a code number according to the Federal Supply Code for Manufacturers; see list of manufacturers below. Parts recommended as spares to sustain operation in isolated locations are indicated in the recommended spare parts column.

Parts manufactured by Electro Scientific Industries must be ordered from the factory. When ordering parts from the factory include the following information:

Model and serial number of the instrument
Electro Scientific Industries part number
Circuit reference designator
Description of part

CODE LIST OF MANUFACTURERS

11837	ELECTRO SCIENTIFIC INDUSTRIES Portland, Oregon

Ckt Ref	Description	Mfr.	ESI Part No.	Qty Used	Recm SP
A_1	Assy, Sw, Res, 100K Per Step	11837	8421	1	
A_2	Ass'y, Sw, Res, 10K Per Step	11837	8422	1	
A_3	Ass'y, Sw, Res, 1K Per Step	11837	8423	1	
A_4	Ass'y, Sw, Res, 100Ω Per Step	11837	8424	1	
A_5	Ass'y, Sw, Res, 10Ω Per Step	11837	8425	1	
A_6	Ass'y, Sw, Res, 1Ω Per Step	11837	8426	1	
A_7	Ass'y, Sw, Res, 0.1Ω Per Step	11837	8427	1	
A_8	Ass'y, Sw, Res, 0.01Ω Per Step	11837	8428	1	

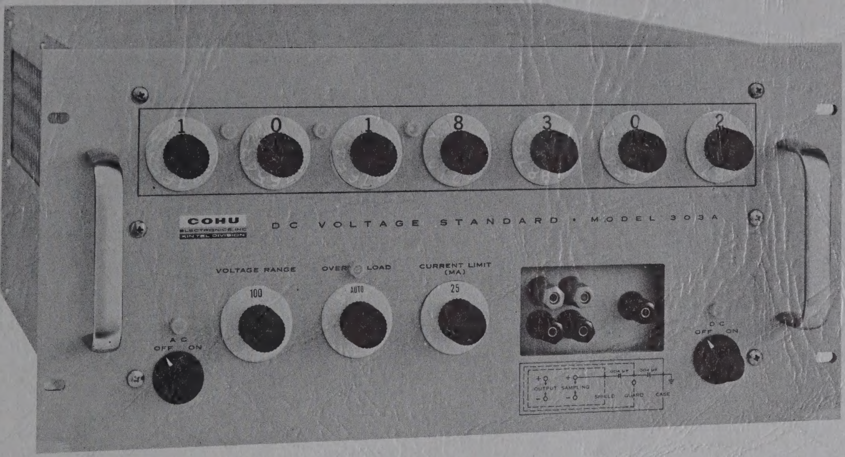
Ckt Ref.	Description	Mfr	ESI Part No.	Qty Used	Recm SP
R_1-R_{11}	Res, Fxd, Precision, 100K, Part of Ass'y A_1	11837	*	11	
R_{12}-R_{21}	Res, Fxd, Precision, 10K, Part of Ass'y A_2	11837	*	10	
R_{22}-R_{31}	Res, Fxd, Precision, 1K, Part of Ass'y A_3	11837	*	10	
R_{32}-R_{41}	Res, Fxd, Precision, 100Ω, Part of Ass'y A_4	11837	*	10	
R_{42}-R_{51}	Res, Fxd, Precision, 10Ω, Part of Ass'y A_5	11837	*	10	
R_{52}-R_{61}	Res, Fxd, Precision, 1Ω, Part of Ass'y A_6	11837	*	10	
R_{62}-R_{71}	Res, Fxd, Precision, 0.1Ω, Part of Ass'y A_7	11837	*	10	
R_{72}	Res, Fxd, Factory adj to 0.01Ω including wiring and sw res	11837	*	1	
R_{73}-R_{80}	Res, Fxd, Precision, 0.01Ω, Part of Ass'y A_8	11837	*	8	
R_{81}	Res, Variable	11837	8446	1	
S_1	Sw, Rot., Part of Ass'y A_1	11837	*	1	
S_2	Sw, Rot., Part of Ass'y A_2	11837	*	1	
S_3	Sw, Rot., Part of Ass'y A_3	11837	*	1	

* Replaces entire ass'y

Ckt Ref	Description	Mfr	ESI Part No.	Qty Used	Recm SP
S_4	Sw, Rot., Part of Ass'y A_4	11837	*	1	
S_5	Sw, Rot., Part of Ass'y A_5	11837	*	1	
S_6	Sw, Rot., Part of Ass'y A_6	11837	*	1	
S_7	Sw, Rot., Part of Ass'y A_7	11837	*	1	
S_8	Sw, Rot., Part of Ass'y A_8	11837	*	1	
	MISCELLANEOUS				
	Dial, Decade, 2nd thru 8th	11837	7807	7	
	Dial, Decade, 1st	11837	7809	1	
	Knob, Bar	11837	1266	8	
	Knob, Round	11837	1271	1	
	Cap, Binding Post, Ins	11837	1294	4	2
	Cap, Binding Post, Metal	11837	1296	1	1
	Window, Decade	11837	7742	8	
	Window, Rheostat	11837	7789	1	
	Slider, Rheostat	11837	4076-2	1	1
	Reversing Drive Ass'y	11837	8817	1	
	Washer, Spring	11837	4264	1	1
	Insulator, Sw stacking bolt	11837	2326	16	

*Replaces entire ass'y

Ckt Ref	Description	Mfr	ESI Part No.	Qty Used	Recm SP
	Washer, Shoulder, Ins	11837	1390	12	



OPERATING AND MAINTENANCE INSTRUCTIONS FOR

DC VOLTAGE STANDARD

MODEL 303A

U. S. AIR FORCE
CONTRACT NUMBER
AF 36(600)-13031

5725 KEARNY VILLA ROAD • SAN DIEGO 12, CALIFORNIA • PHONE 277-6700 •

COHU
ELECTRONICS, INC
KIN TEL DIVISION

MANUAL PRICE $10.00

Technical Manual
Code No. 15X-31

U. S. AIR FORCE
CONTRACT NUMBER
AF 36(600)-13031

OPERATING AND MAINTENANCE INSTRUCTIONS FOR MODEL 303A DC VOLTAGE STANDARD

FSN 6625-994-8679

COHU ELECTRONICS, INC.
KIN TEL Division
5725 Kearny Villa Road
Box 623
San Diego 12, California

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19 NOVEMBER 1962

TABLE OF CONTENTS

Section	Page
I GENERAL DESCRIPTION	1-1
1-1. Introduction	1-1
1-2. Physical Details	1-1
1-3. Shielding	1-1
1-4. Printed Circuit Boards	1-2
1-5. Dimensions and Weight	1-2
1-6. Electrical Specifications	1-2
1-7. Accessories	1-2
II OPERATION	2-1
2-1. Installation	2-1
2-2. Terminal Connections	2-1
2-3. Two-Terminal Output	2-1
2-4. Four-Terminal Output	2-1
2-5. Output Cables	2-1
2-6. Rear Terminal Kit	2-3
2-7. Primary Power Connection	2-3
2-8. Operating Controls	2-3
2-9. Functional Check	2-4
2-10. Operating Procedure	2-5
2-11. Output Voltage Dials	2-5
III THEORY OF OPERATION	3-1
3-1. General Theory of Operation	3-1
3-2. Detailed Theory of Operation	3-2
3-3. Power Supplies	3-2
3-4. Reference Unit	3-2
3-5. Voltage Range Control Circuit	3-2
3-6. Resistance Decade	3-2
3-7. Carrier Amplifier	3-3
3-8. Demodulator	3-3
3-9. Wideband Amplifier	3-4
3-10. Direct-Coupled Output Amplifier	3-4
3-11. Output Tube	3-5
3-12. Protective Circuits	3-6
IV MAINTENANCE	4-1
4-1. General	4-1
4-2. Disassembly and Parts Location	4-1
4-3. Preventive Maintenance	4-1

TABLE OF CONTENTS (CONTD)

Section Page

4-4. General Cleaning 4-1

4-5. Air Filter 4-3

4-6. Fan Motor 4-3

4-7. Relays 4-3

4-8. Switches 4-3

4-9. Chopper 4-4

4-10. Performance Check 4-4

4-11. Calibration 4-4

4-12. Troubleshooting 4-8

4-13. Trouble Localization . . 4-8

4-14. Trouble Locating 4-9

4-15. Internal Adjustments . . 4-11

4-16. Schmitt Trigger Bias Level Adjustment 4-13

4-17. DC Balance Adjustment 4-13

4-18. Corrective Maintenance 4-13

4-19. Replacement Parts and Recommended Spares 4-14

LIST OF ILLUSTRATIONS

Figure Page

1-1. Model 303A DC Voltage Standard 1-1

1-2. Shielding System 1-2

1-3. Dimensions and Outline 1-3

2-1. Positive, Two-Terminal Output Connections 2-2

2-2. Negative, Two-Terminal Output Connections 2-2

2-3. Positive, Four-Terminal Output Connections 2-2

2-4. Negative, Four-Terminal Output Connections 2-2

2-5. Output Cable 2-3

3-1. Model 303A, Block Diagram 3-1

3-2. Range Control Switching, Simplified Schematic Diagram. . . . 3-3

3-3. Carrier Amplifier, Simplified Schematic Diagram 3-4

3-4. Demodulator, Simplified Schematic Diagram 3-5

3-5. Wideband Amplifier, Simplified Schematic Diagram 3-6

3-6. DC Output Amplifier, Simplified Schematic Diagram 3-7

3-7. Output Tube Circuits, Simplified Schematic Diagram 3-7

3-8. Over-Voltage Protective Circuit, Simplified Schematic Diagram 3-8

3-9. Over-Current Protective Circuits, Simplified Schematic Diagram . . . 3-10

4-1. Component Location, Rear View 4-1

4-2. Component Location, Top View 4-2

4-3. Component Location, Bottom View 4-2

4-4. Calibration Connections, Zero Volt Output Adjustment 4-5

4-5. Calibration Connections, Linearization 4-5

4-6. Calibration Connections, Linearization 4-5

4-7. Calibration Connections, Scale Adjustment. 4-5

4-8. Protective Circuits . . . 4-10

4-9. Check Point Locations . . 4-11

LIST OF ILLUSTRATIONS (CONTD)

Figure Page

4-10. Normal Waveforms. . . . 4-12

4-11. Power Supply Board, Component Locations. . . 4-14

4-12. DC Output Amplifier and Protective Circuits Board, Component Locations 4-14

4-13. Carrier and Wideband Amplifiers Board, Component Locations. . . 4-15

4-14. Resistance Decade Board, Component Locations 4-15

4-15. Chopper Board, Component Locations. . . 4-16

4-16. High Voltage Power Supply, Component Locations 4-16

4-17. High Voltage Power Supply Board, Schematic Diagram (Drawing No. C7813500B). 4-16

Figure Page

4-18. Power Supply Circuit Board, Schematic Diagram (Drawing No. D7813100C). 4-17

4-19. Carrier and Wideband Amplifiers Circuit Board, Schematic Diagram (Drawing No. D7813200A) 4-18

4-20. DC Output Amplifier Circuit Board, Schematic Diagram (Drawing No. 7813300G) 4-19

4-21. Resistance Decade Circuit Board, Schematic Diagram (Drawing No. D7813410) 4-20

4-22. Model 303A, Overall Schematic Diagram (Drawing No. J7813902D) 4-21, 4-22

LIST OF TABLES

Table Page

1-1. Electrical Specifications. 1-4

2-1. Examples of Output Voltage Dials' Settings Using the X Positions . . 2-6

Table Page

4-1. List of Replacement Parts 4-23

4-2. Spare Parts Kits 4-47

Section I
GENERAL DESCRIPTION

1-1 INTRODUCTION

The Model 303A DC Voltage Standard (Figure 1-1) is an exceptionally stable source of precisely adjustable DC voltage covering a range of 0 to ±1111.1110 volts. Output voltage accuracy is within 0.01 percent of the voltage indicated by the setting of the instrument dials. Accuracy within specifications is maintained with extended leads to the load using a four-terminal output technique.

The output voltage is set by a three-position range control and seven eleven-position controls that give an in-line readout of the output voltage. A four-position control allows the output current to be limited to 5, 10, 15, and 25 milliamperes. Overload protection circuits, which can be reset manually or automatically, disconnect the output voltage from the load should (a) the load voltage exceed the voltage to which the instrument is set, or (b) the load current exceeds the limit to which the current limit control is set; overload also causes an indicator to light. The instrument circuits are fully isolated from ground, shielded, and guarded, and can be used either floating or grounded.

1-2 PHYSICAL DETAILS

The dimensions of the instrument are such that it can be mounted in a standard 19-inch rack, or it can be used as a cabinet model. All controls, indicators, and binding posts are mounted on the front panel. The primary power fuse and entry, and the cooling fan are located at the rear.

1-3. SHIELDING. The instrument circuits are enclosed by two insulated metal shields in addition to the outer case. The inner shield is permanently connected to circuit common, the middle shield is connected to the GUARD terminal, and the outer case is

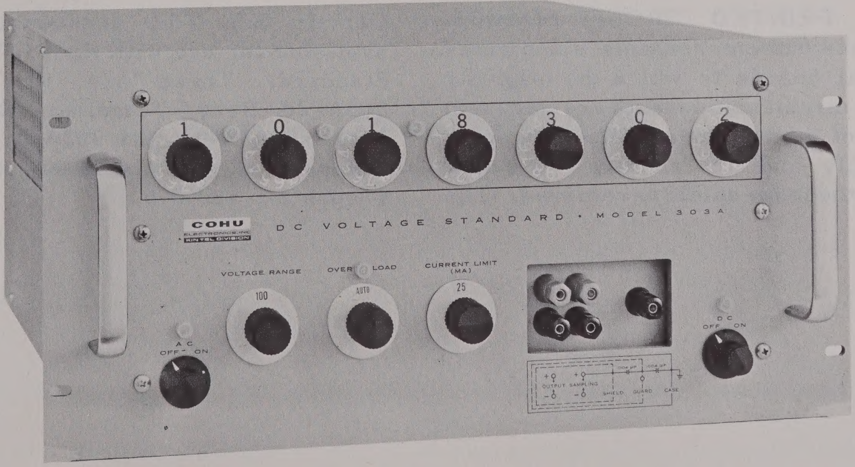


Figure 1-1. Model 303A DC Voltage Standard

grounded through the ground lead of the AC input cable. This system of shielding permits operation of the instrument circuits with up to 1500-volt potential difference between the GUARD shield and the outer case. Common mode voltages produce negligible errors. When shields are properly used disturbances in external circuits can be minimized. Distributed capacity between enclosures is indicated in Figure 1-2.

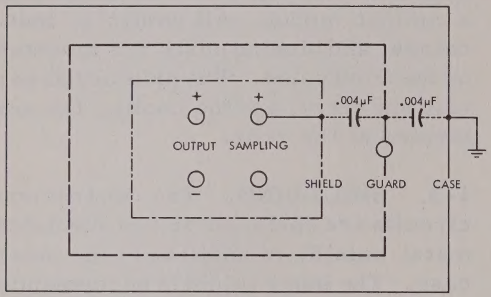


Figure 1-2. Shielding System

1-4. PRINTED CIRCUIT BOARDS. The instrument contains six printed circuit boards to which the majority of the circuit components are secured. Five of the boards are mounted horizontally and are readily accessible when the inner shield is removed. The remaining board is mounted vertically immediately behind the output voltage controls and holds the range and decade resistors, and a capacitor. The resistors on this board are selected by the voltage range switch and the seven eleven-position switches for setting the output voltages. Variable trimming resistors on this board can be adjusted through holes in the top plate of the inner shield.

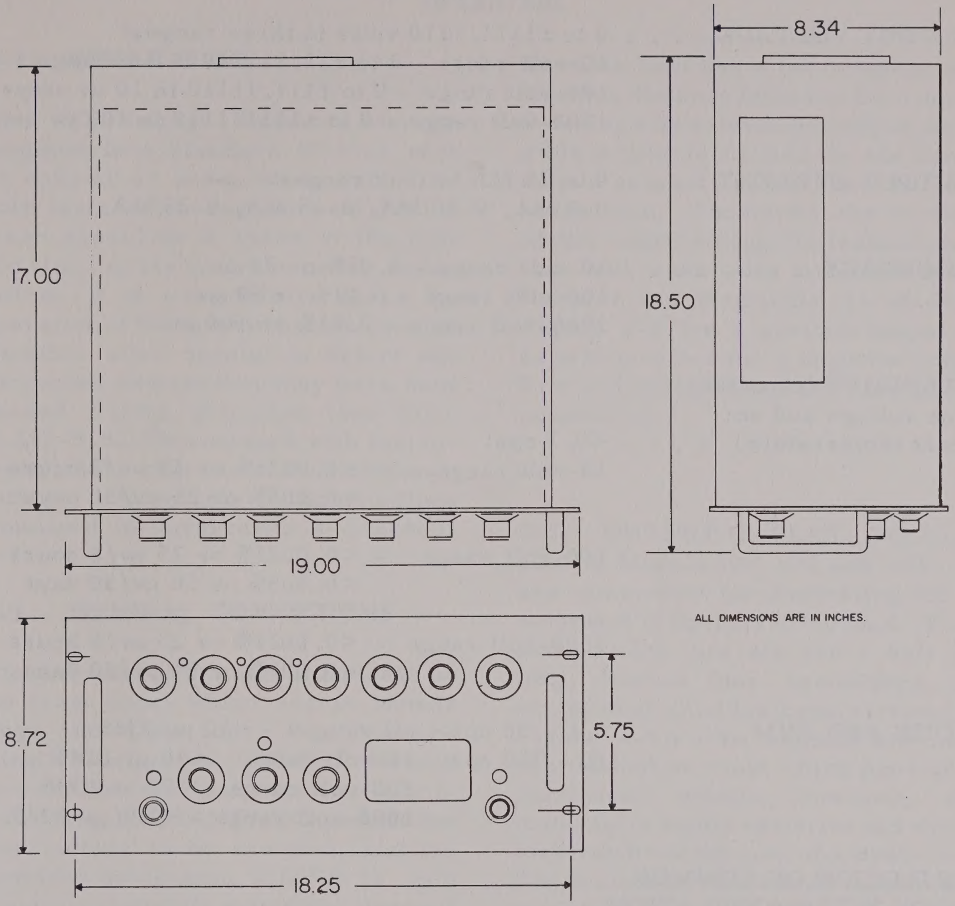
1-5. DIMENSIONS AND WEIGHT. The dimensions and outline of the instrument are shown in Figure 1-3. The net weight is 65 pounds and the shipping weight is 85 pounds.

1-6 ELECTRICAL SPECIFICATIONS

The electrical performance specifications of the instrument are listed in Table 1-1.

1-7 ACCESSORIES

Certain KIN TEL accessories are available for use with the DC Voltage Standard. These are the Model 303A-20 Rear Terminal Kit and Models 303A-11 and 303A-12 Output Cables, and are discussed in paragraphs 2-5 and 2-6.



ALL DIMENSIONS ARE IN INCHES.

Figure 1-3. Dimensions and Outline

Table 1-1. Electrical Specifications

OUTPUT VOLTAGE	0 to ±1111.1110 volts in three ranges: 10-volt range - 0 to ±11.111110 in 1 μv steps 100-volt range - 0 to ±111.11110 in 10 μv steps 1000-volt range - 0 to ±1111.1110 in 100 μv steps
OUTPUT CURRENT	0 to 25 MA in four ranges: 0-5 MA, 0-10 MA, 0-15 MA, 0-25 MA
ACCURACY	10-volt range - 0.01% or 25 μv 100-volt range - 0.01% or 50 μv 1000-volt range - 0.01% or 100 μv
STABILITY (constant line voltage and ambient temperature)	<0.1 cps: 10-volt range - <0.0025% or 13 μv/8 hours <0.005% or 25 μv/30 days 100-volt range - <0.0025% or 25 μv/8 hours <0.005% or 50 μv/30 days 1000-volt range - <0.0025% or 25 μv/8 hours <0.005% or 50 μv/30 days
NOISE AND HUM	0.1 - 10 cps: all ranges - <10 μv RMS 10 - 750 cps: 10-volt range - <40 μv RMS 100-volt range - <70 μv RMS 1000-volt range - <100 μv RMS
REJECTION OF COMMON MODE INTERMODULATION PRODUCTS (DC offset against RMS AC between Guard and outer case)	10^{-6} at 60 cps
SOURCE IMPEDANCE	($0.001 + 0.0004E_{out}$) ohm maximum
LOAD REGULATION	<0.001% or 25 μv no load to full load
LINE REGULATION	<0.001% or 10 μv for 10% line change
TEMPERATURE COEFFICIENT	<5 parts/million/°C from +15°C to +35°C
POWER INPUT	105 to 125 or 210 to 250 volts, 50 or 60 cps, 125VA
MAXIMUM WARM-UP TIME	15 minutes to 0.01% 30 minutes to complete stabilization

Section II
OPERATION

2-1 INSTALLATION

The DC Voltage Standard may be mounted in a standard 19-inch rack or cabinet or used unmounted. The only installation requirement is that there should be a space at the rear and sides of the instrument for ventilation. It is advisable to check the operation of the instrument as soon as possible after receipt to detect any concealed damage that may have been caused during shipment (see form P-293-5-62-5M enclosed with instrument); make this check in accordance with the information and instructions contained in paragraphs 2-2 through 2-9.

2-2 TERMINAL CONNECTIONS

The instrument has five terminals on the front panel which accept banana plugs and spade lugs. The two terminals designated OUTPUT furnish current for the load, the two terminals designated SAMPLING permit the load voltage to be sampled, and the terminal designated GUARD is used to electrostatically shield the internal circuits. Either two-terminal or four-terminal outputs may be used and the terminals can be connected so as to provide positive or negative, grounded or floating outputs.

2-3. TWO-TERMINAL OUTPUT. Two-terminal output should be used only when the load is close to the instrument. In this case, connect the terminals as shown in Figure 2-1 for a positive output and as in Figure 2-2 for a negative output. For a floating output omit the ground connection.

2-4. FOUR-TERMINAL OUTPUT. Four-terminal output should be used when the load has a low impedance or is some distance from the instrument. By using a four-terminal output, negligible error is caused by the flow of output current in the external leads to the load. Therefore, the accuracy of the output voltage is maintained at the load even with extended leads. Connect the terminals as shown in Figure 2-3 for a positive output and as in Figure 2-4 for a negative output. For a floating output omit the ground connection.

2-5. OUTPUT CABLES. The output cables, Models 303 -11 and 303 -12, are convenient for connecting the instrument terminals to the load. These accessories are six and a half feet long, contain four conductors, and are of dual shielded construction (see Figure 2-5). The shields are made of a conductive vinyl which provides a continuous shield. However, this material is highly resistive and therefore requires the use of a drain lead. The drain lead is a small copper wire wound loosely around the cable making contact along the inside of the conductive vinyl shield. This arrangement reduces the resistance per unit length of the shield.

Model 303 -11 has spade lugs at both ends and Model 303 -12 has spade lugs at one end only. The leakage resistance between conductors is a minimum of 100,000 megohms per foot. The voltage rating between conductors, between shields, and between conductors and shields is 1000 volts RMS. Both models use No. 16 wire and the total resistance for each loop is 0.052 ohm.

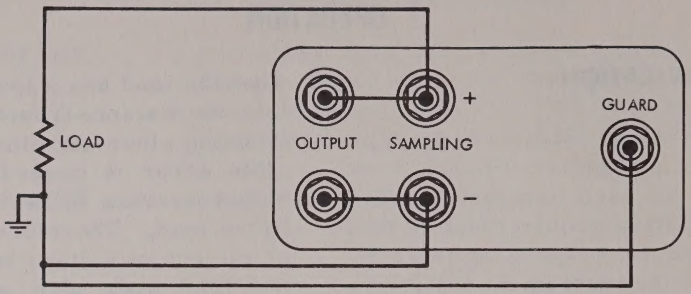


Figure 2-1. Positive, Two-Terminal Output Connections

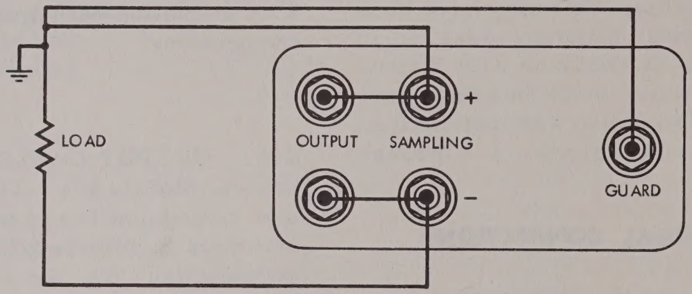


Figure 2-2. Negative, Two-Terminal Output Connections

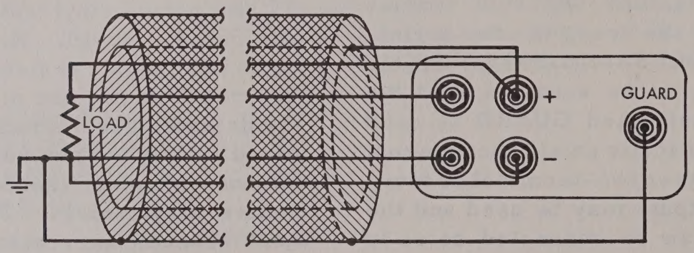


Figure 2-3. Positive, Four-Terminal Output Connections

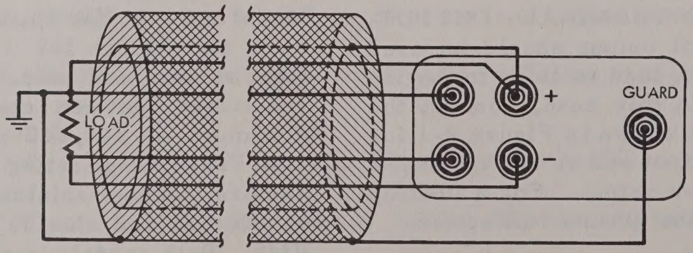


Figure 2-4. Negative, Four-Terminal Output Connections

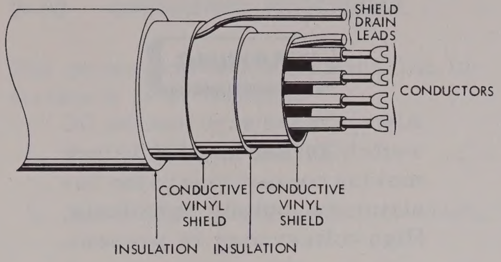


Figure 2-5. Output Cable

2-6. REAR TERMINAL KIT. If the instrument is equipped with Rear Terminal Kit, Model 303A-20, connections may be made at the front terminals OR the rear terminals, but NEVER at both.

NOTE

> Before making connections to either the front or rear terminals make sure that the other set of terminals is free of all connections.

2-7 PRIMARY POWER CONNECTION

The instrument should be used connected to a three-contact outlet so that the outer case is grounded. If the instrument is operated from a two-contact outlet, use a three contact adapter with a pigtail, and connect the pigtail to ground.

2-8 OPERATING CONTROLS

All operating controls are mounted on the front panel of the instrument and are used as follows:

AC switch:
Turns on and off the AC power to the instrument. The associated indicator lights when the power is turned on.

DC switch:
Connects and disconnects the output voltage to the output terminals. The associated indicator lights when the output terminals are energized.

VOLTAGE RANGE switch:
Permits the 10, 100, or 1000 volts range to be selected.

Decimal Point Indicator:
When a range is selected the appropriate decimal point indicator lights.

Output Voltage Switches:
Set for the desired output voltage. The switch dials indicate numerically the output voltage.

CURRENT LIMIT (MA) switch:
Permits the output current to be limited to 5, 10, 15, or 25 milliamperes.

OVER LOAD switch and indicator:
RESET, MAN, and AUTO positions, with spring return to MAN position from RESET. When an overload occurs with the switch in the MAN position, the overload protection circuits are reset manually by positioning the switch to RESET. The OVER LOAD indicator lights during overload.

When an overload occurs with the switch in the AUTO position, the protection circuits reset automatically and the OVER LOAD indicator flashes on and off while the overload persists. The DC indicator also will flash on and off unless the DC switch is in the OFF position.

2-9 FUNCTIONAL CHECK

A functional check of the instrument may be made in accordance with the following procedure:

a. Set AC and DC switches to OFF.

b. Set each output voltage dial to indicate 0.

c. Set OVER LOAD switch to MAN.

d. Set CURRENT LIMIT (MA) switch to 25.

e. Connect together OUTPUT and SAMPLING positive terminals, and connect together OUTPUT and SAMPLING negative terminals.

f. Set VOLTAGE RANGE switch to 10.

g. Set AC switch to ON. The AC and OVER LOAD indicators and left decimal point indicator should light, and the fan should operate.

h. Wait approximately one minute for the instrument to stabilize.

i. Set OVER LOAD switch to RESET and let it return to the MAN position. The OVER LOAD indicator should extinguish. The indicator will not extinguish if the stabilization time allowed is insufficient; in this case, repeat the instruction in this step. If the instrument fails to reset after a number of attempts a fault has developed.

j. Connect the instrument to a digital voltmeter, or a microvolt meter having 1-millivolt through 10-volt ranges.

WARNING

Always make sure that the DC switch is set at OFF before making connections to the instrument output terminals. High voltage may be present.

k. Set DC switch to ON. The DC indicator should light.

l. Starting with the output voltage dial at the extreme left, set the dial to each position in turn. Compare each setting of the DC Voltage Standard with the voltage indicated by the voltmeter. Return the dial to the 0 volt position.

m. Set VOLTAGE RANGE switch to 100 and repeat the instructions in step l using the second dial from the left.

n. Set VOLTAGE RANGE switch to 1000 and repeat the instructions in step l using the third dial from the left.

o. Repeat the instructions in step l using the fourth dial from the left and then repeat the procedure for each of the three remaining dials in turn finishing with the one at the extreme right.

p. Complete the functional check by setting the CURRENT LIMIT (MA) switch to 15, 10, and then 5 with the output voltage dials at any setting within the range of the readout device. The voltage indicated by the readout device should not change and the protective circuits should not trip.

q. Set DC switch to OFF.

2-10 OPERATING PROCEDURE

The procedure for operating the instrument is as follows:

a. Set DC switch to OFF.

b. Set OVER LOAD switch to MAN.

c. Set AC switch to ON and allow approximately one minute for stabilization.

d. Reset the overload protective circuits.

e. Set OVER LOAD switch to AUTO.

f. Make sure DC switch is set at OFF and then make connections to instrument terminals (see WARNING below).

g. Determine load current required and set CURRENT LIMIT (MA) switch accordingly.

h. Set instrument for required output voltage using VOLTAGE RANGE switch and the seven output voltage switches (refer to paragraph 2-11).

i. Set DC switch to ON.

As a safety precaution the DC switch should be set at OFF when the instrument is on standby.

WARNING

Do not change the connections at the instrument terminals or connect or disconnect the load when the DC switch is set at ON. The instrument may be set for a high output voltage.

2-11 OUTPUT VOLTAGE DIALS

The seven output voltage dials can each be set to positions 0 through 9 and X, except the highest decade dial (extreme left) which has positions 0 through 10. The X position of a dial indicates a voltage equal to ten times that of position 1 of the same dial and equal to the voltage indicated by position 1 of the next higher decade dial. Use of the X positions permits most output voltages to be set using more than one setting of the dials. Therefore, comparison of the same voltage set by different range and dial settings can be made; this provides a linearity self-check feature for all ranges. Sometimes it is more convenient to use the X positions to obtain a desired output voltage; to obtain the maximum voltage it is a necessity. The examples of dial settings in Table 2-1 illustrate the points discussed in this paragraph.

Table 2-1. Examples of Output Voltage Dials' Settings Using the X Positions

FEATURE	DIALS' SETTING	OUTPUT VOLTAGE
Convenient to use the X position to switch from 199.9 to 200 volts	199.9000	199.9
	199.X000	200
Linearity self-check (100-volt range)	49.9999X	50
	49.999X0	50
	49.99X00	50
	49.9X000	50
	49.X0000	50
	4X.00000	50
	50.00000	50
Necessary use of the X positions (only one setting possible)	10XX.XXXX	1111.1110

Section III

THEORY OF OPERATION

3-1 GENERAL THEORY OF OPERATION

The Model 303A will supply voltages within specifications at the load, even when the instrument and its load are widely separated, through use of a four-terminal output technique. This permits the instrument circuits to regulate the voltage at the load since the extremely small current flow in the sampling leads introduces negligible error in the voltage sampled at the load. The error voltage for the system is derived from a reference voltage source, range resistors, and a resistance decade. The range resistors are selected by the voltage range switch. The seven output voltage switches control the total resistance of the resistance decade. A constant current from the reference unit, as determined by the range resistor selected, develops a voltage across the decade resistors selected. This voltage is the output voltage of the instrument.

The summing junction (see Figure 3-1) is normally at zero potential with respect to circuit common (+SAMPLING terminal). When the setting of the output voltage dials or voltage range control is changed the voltage developed across the resistance decade changes. The magnitude of this voltage is now different from that across the OUTPUT terminals and a difference (or error) voltage appears at the summing

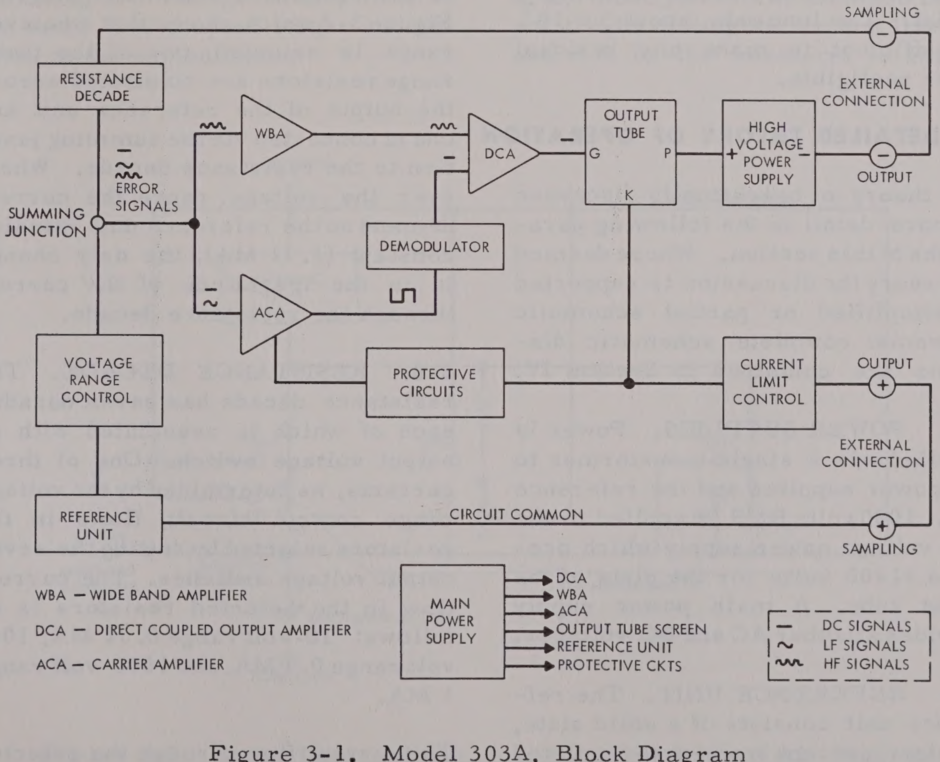


Figure 3-1. Model 303A, Block Diagram

junction and is applied to the carrier and wideband amplifiers. The DC and lower frequency components of the error voltage are chopper-modulated and amplified by the carrier amplifier. The output of the carrier amplifier is demodulated and applied to the direct-coupled output amplifier(DCA). The higher frequency components of the error voltage are amplified by the wideband amplifier the output of which also is applied to the DCA. The output of the DCA drives the control grid of the output tube. The output tube is connected in series with the high voltage power supply, the current limit control circuit, and the load.

The control grid of the output tube controls the magnitude of the output current so that the voltage across the load is equal to the dial setting. This maintains the summing junction at zero potential. The loop gain, about 3 x 10^7, is sufficient to make any residual error negligible.

3-2 DETAILED THEORY OF OPERATION

The theory of operation is discussed in more detail in the following paragraphs of this section. Where deemed necessary the discussion is supported by simplified or partial schematic diagrams; complete schematic diagrams are contained in Section IV.

3-3. POWER SUPPLIES. Power is supplied via a single transformer to two power supplies and the reference unit. 1000 volts RMS is applied to the high voltage power supply which provides +1400 volts for the plate of the output tube. A main power supply provides all other AC and DC voltages.

3-4. REFERENCE UNIT. The reference unit consists of a solid state, constant current type, pre-regulated circuit in an electronically controlled oven which is maintained at a temperature of 70 $^{+0}_{-5}$ degrees Centigrade, stable to within 0.1 degree. The oven is powered by 15-volt and 25-volt windings on the power transformer, and the reference circuit by 22 volts DC from the main power supply. The output voltage is approximately 6 volts DC when used to provide a constant current reference. The reference unit is provided with a constant current load by the voltage range control circuit.

3-5. VOLTAGE RANGE CONTROL CIRCUIT. Regardless of the value of the range resistor selected by the setting of the voltage range switch, the range control circuit always present a constant load to the output of the reference unit. This is illustrated in the simplified schematic diagram Figure 3-2 which shows that whatever range is selected, two of the three range resistors are connected across the output of the reference unit and one is connected via the summing junction to the resistance decade. Whatever the voltage range the current demand on the reference unit remains constant (1.11 MA); the only change is in the magnitude of the current through the resistance decade.

3-6. RESISTANCE DECADE. The resistance decade has seven decades each of which is associated with an output voltage switch. One of three currents, as determined by the voltage range control circuit, flows in the resistors selected by setting the seven output voltage switches. The current flow in the selected resistors is as follows: 10-volt range 0.01 MA, 100-volt range 0.1 MA, and 1000-volt range 1 MA.

The current flow through the selected

resistors determines the output voltage of the instrument. With the output voltage as indicated by the output voltage dials, the summing junction is very nearly at zero potential with respect to circuit common (+SAMPLING terminal). A difference between the voltage across the resistance decade and the output voltage of the instrument appears as an error voltage at the summing junction and is applied to the carrier and wideband amplifiers.

3-7. CARRIER AMPLIFIER. The carrier amplifier consists of a chopper D801 and three conventional amplifying stages (see Figure 3-3). The chopper is activated by 6.3 volts AC and converts the DC and lower frequency components of the error voltage to a pulsating DC voltage at the rate of 60 cycles per second. The pulsating DC voltage is amplified by the three R-C coupled stages and applied to the demodulator.

A part of V203 output is demodulated and applied to the control-grid circuit of V202 and serves to stabilize the wideband amplifier and reduce overload recovery time.

3-8. DEMODULATOR. The demodulator consists of a circuit for phase sensitive detection of the carrier amplifier output. This circuit demodulates the carrier amplifier output which is applied to the direct-coupled output amplifier.

Transformer T901 drives the demodulator circuit with a 60-cps voltage phased with the voltage that drives the chopper. When CR305 and CR306 conduct, the diode junction is equal to that determined by the DC voltage divider consisting of R111, R356, and R350 through R353. Thus, the voltage at the diode junction is clamped at the point indicated by the broken line and asterisk on the waveform in Figure

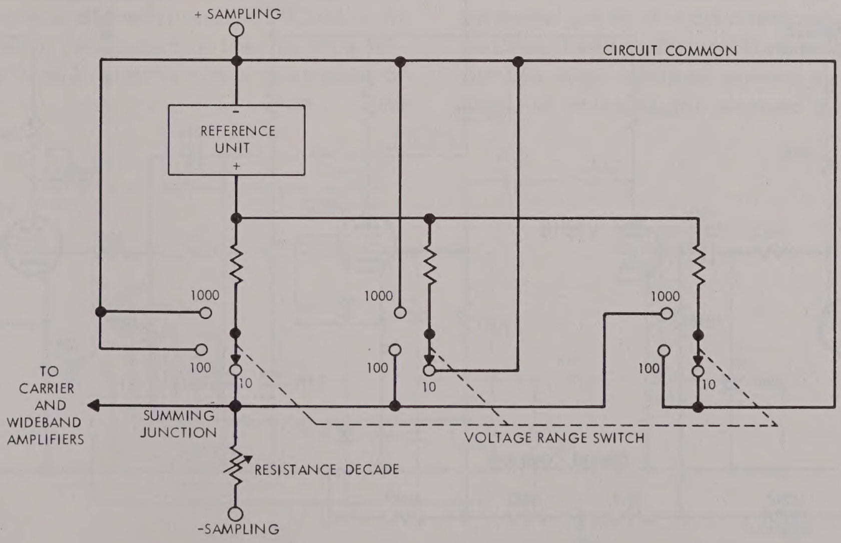


Figure 3-2. Range Control Switching, Simplified Schematic Diagram

3-4. The phase shift of the amplifier and chopper drive is such that the diodes are conducting when the chopper open signal arrives at the amplifier output.

The network comprised of R350 through R354 provides proper biasing for the control grid of V303 in the output stage of the direct-coupled amplifier.

3-9. WIDEBAND AMPLIFIER. The wideband amplifier consists of two amplifying stages, an overload compensation circuit, and a stabilizing circuit (see Figure 3-5). The wideband amplifier amplifies the higher frequency components of the error voltage and applies them to the direct-coupled output amplifier.

The output of V201A is R-C coupled to V202 via the overload compensation circuit, R209 and C206. The demodulated output of V203 in the carrier amplifier also is applied to V202 via the overload compensation circuit and the stabilizing circuit, R206, R222, neon lamp DS201, and R207. During transient overload conditions, the increased output of V203 ionizes the neon lamp and thereby increases the flow of current in the stabilizing circuit. The resulting increase in voltage across R207 reduces the time required for return to normal operation. When the output of V203 returns to its normal level the neon lamp de-ionizes.

3-10. DIRECT-COUPLED OUTPUT AMPLIFIER. The DC output amplifier consists of two cathode follower stages

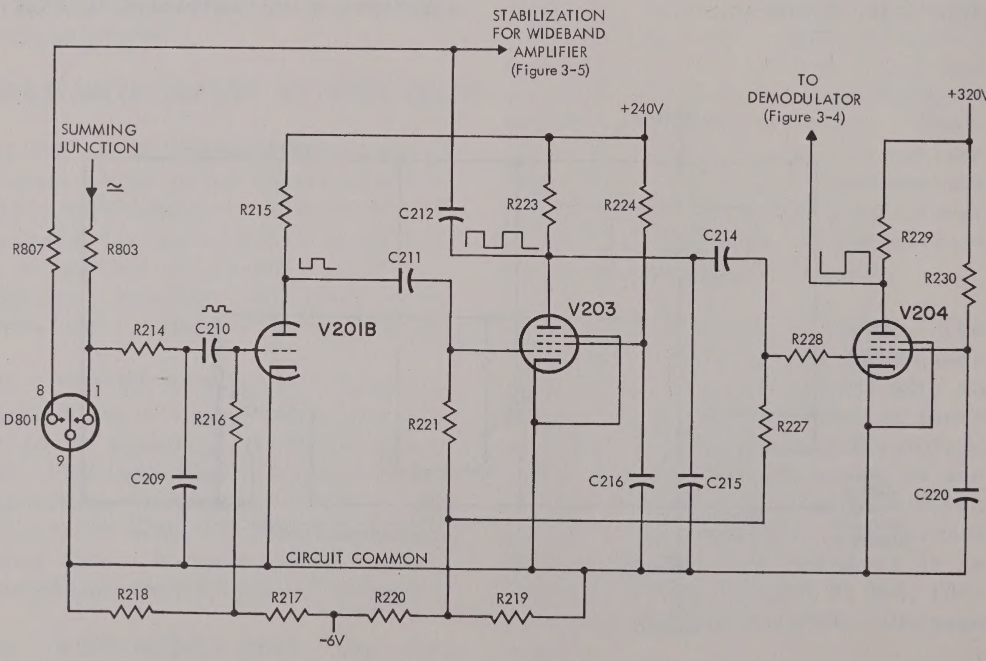


Figure 3-3. Carrier Amplifier, Simplified Schematic Diagram

and a pentode amplifier stage arranged in two parallel circuits (see Figure 3-6). The carrier and wideband amplifiers drive the DC output amplifier which in turn drives the output tube.

The demodulated output of the carrier amplifier is applied via R348 to the grid of cathode follower V303A where it is combined with the output of the wideband amplifier which is coupled by C309. The output of V303A is directly coupled to the cathode of pentode V303B. The output of the pentode is applied directly to the control grid of the output tube. Variable resistor R352 permits the grid bias of the pentode to be adjusted to obtain DC balance.

The output of the wideband amplifier is also coupled by C308 to the control grid of cathode follower V302. The output of V302 is applied via C307 to the control grid of the output tube. Tube V302 passes the higher frequency components of the error voltage that are beyond the response of V303. At the lower frequencies the loading effect of V302 modifies the response of V303.

The pentode V303B drives the output tube at DC and the medium frequencies of the error voltage; at these frequencies V303B provides large voltage gain with relatively large swing within a medium bandwidth. At the higher frequencies V302 provides a lower voltage swing capability but much lower output impedance, therefore, at frequencies above that at which the gain of V303B is unity the output tube is driven by V302.

Feedback from the output of the DC output amplifier, applied via C311 and R355 (also shown in Figure 3-5) to the second stage of the wideband amplifier, largely determines and stabilizes the transfer function of these stages.

3-11. OUTPUT TUBE. The DC output amplifier drives the output tube which changes the output voltage so that the summing junction voltage approaches zero.

The output tube circuits (see Figure 3-7) include two voltages that are not referenced to circuit common. These are the 1400 volts applied to the plate by the high voltage power supply and the 125 volts at the screen grid. The

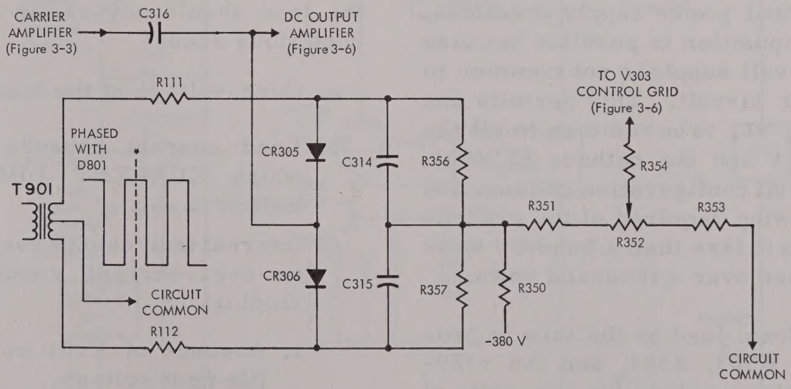


Figure 3-4. Demodulator, Simplified Schematic Diagram

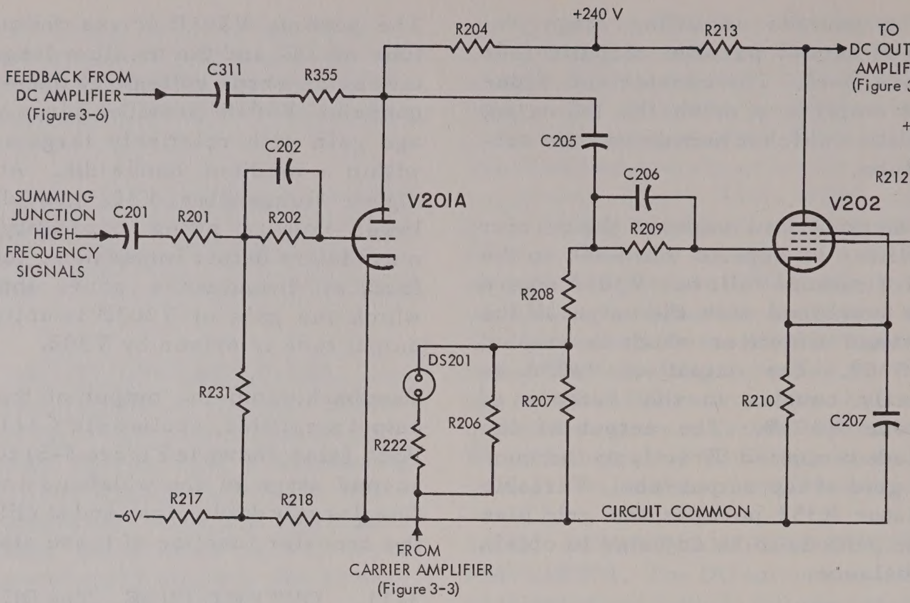


Figure 3-5. Wideband Amplifier, Simplified Schematic Diagram

output tube, V901, is connected in series with the high voltage power supply, the current limit control circuit, and the load. The load and the plate supply are transposed so that the output tube is a voltage amplifier rather than a cathode follower as in conventional power supply practices. The transposition is possible because the 1400-volt supply is not common to any other circuit. This permits one terminal, +e, to be common to all the amplifiers and the cathode of V901. This circuit configuration reduces the voltage swing required of the preceding stages to less than a hundred volts rather than over a thousand volts.

An additional load on the tube is provided by R503, R504, and the +380-volt supply avoiding the necessity of complete cut off when the output voltage dials are set for zero volts.

Resistors R914 and R915 provide a discharge path for the output capacitor, C902.

3-12. PROTECTIVE CIRCUITS. The protective circuits protect the instrument by disconnecting the output from the load should any of the following conditions occur:

a. Over-voltage at the load.

b. Load current exceeds limit to which CURRENT LIMIT (MA) switch is set.

c. Internal fault causes over-voltage or over-current condition, including:

  1. Absence of V201 or V203 DC filament voltage.

  2. Open circuit filament of V201 or V203.

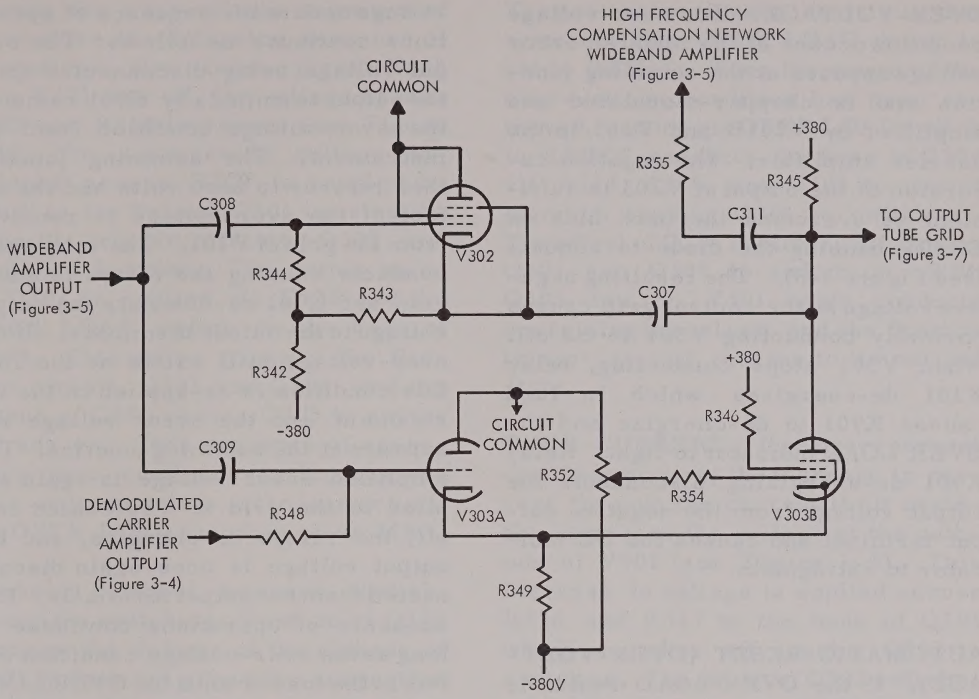

HIGH FREQUENCY COMPENSATION NETWORK WIDEBAND AMPLIFIER (Figure 3-5)
CIRCUIT COMMON
+380
R355
R345
C308
C311
TO OUTPUT TUBE GRID (Figure 3-7)
WIDEBAND AMPLIFIER OUTPUT (Figure 3-5)
V302
R344
R343
C307
R342
+380
R346
-380
CIRCUIT COMMON
C309
R352
R354
DEMODULATED CARRIER AMPLIFIER OUTPUT (Figure 3-4)
R348
V303A
V303B
R349
-380V

Figure 3-6. DC Output Amplifier, Simplified Schematic Diagram

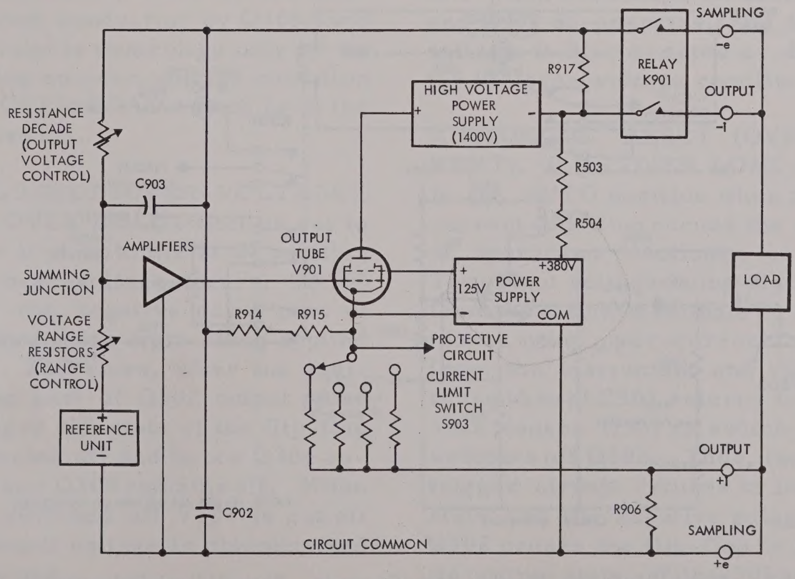


Figure 3-7. Output Tube Circuits, Simplified Schematic Diagram

OVER-VOLTAGE. If an over-voltage condition occurs at the load, an error voltage appears at the summing junction and is chopper-modulated and amplified by V201B and V203 in the carrier amplifier. The negative excursion of the output of V203 is sufficient to overcome the back bias on CR301 causing the diode to conduct (see Figure 3-8). The resulting negative voltage at the control grid causes normally conducting V301 to cut off. When V301 stops conducting, relay K301 de-energizes which in turn causes K901 to de-energize and the OVER LOAD indicator to light. Relay K901 de-energizing disconnects the output voltage from the negative output terminal and causes the DC indicator to extinguish.

AUTOMATIC RESET (OVER-VOLTAGE). If the OVER LOAD switch is in the AUTO position when an over-voltage occurs the sequence of operations continues as follows: The output voltage being disconnected from the output terminals by K901 removes the over-voltage condition from the instrument. The summing junction then returns to zero volts and the effect of the over-voltage is removed from the grid of V301. The tube again conducts causing the relays to energize and K901 re-connects the output voltage to the output terminals. If the over-voltage still exists at the load this condition is re-applied to the instrument and the error voltage reappears at the summing junction. The amplified error voltage is again applied to the grid of V301 which cuts off, the relays de-energize, and the output voltage is once again disconnected from the output terminals. This sequence of operations continues as long as the over-voltage condition exists at the load or until the OVER LOAD switch is set to MAN.

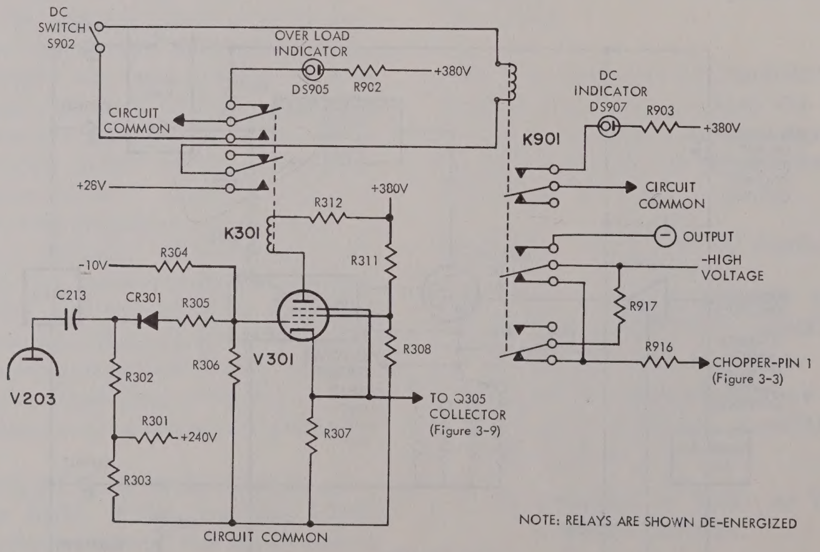


Figure 3-8. Over-Voltage Protective Circuit, Simplified Schematic Diagram

During the over-voltage sequence of operations the following sequence of operations also takes place: Each time V301 cuts off, the voltage across R309 and R310 increases (see Figure 3-9). The increase in voltage developed across R309 is coupled by C304 to the base of Q301 causing the Schmitt trigger circuit, Q301 and Q302, to function. The output pulse of Q302 is applied via C305 and the OVER LOAD switch to the base of Q303. This pulse triggers the flip-flop circuit, Q303 and Q304, and the output of Q303 causes Q305 to switch off and on. This sequence of operations also continues as long as the over-voltage exists at the load or until the OVER LOAD switch is set to MAN.

It should be noted, however, that although the switching off and on of Q305 changes the voltage at the cathode of V301 it does not affect the conduction of V301. This is due to the fact that Q305 is on (normal state) at the instant the effect of the over-voltage condition is removed from the grid of V301. Therefore, V301 is not prevented from conducting by Q305, and thus the tube is controlled only by its grid during an over-voltage condition when the OVER LOAD switch is in the AUTO position.

MANUAL RESET (OVER-VOLTAGE). When the OVER LOAD switch is set to MAN, or if it is in the MAN position when an over-voltage occurs, CR303 prevents the negative going part of Q302 output pulse from being applied to Q303. Therefore, after the positive going part of Q302 output pulse has changed the state of the flip-flop, Q303 remains off and hence Q304 remains on and Q305 remains off. When Q305 is switched off V301 is cut off and the output voltage is disconnected from the load.

The protective circuits remain in this state until the OVER LOAD switch is set to RESET. When the cause of the over-voltage condition has been removed, setting the OVER LOAD switch to RESET connects the base of Q304 via R314, R315, and C303 to circuit common causing Q304 to switch off. The effect of Q304 switching off causes Q303 and Q305 to switch on. With Q305 now on, V301 again conducts energizing the relays, and the Schmitt trigger circuit returns to its normal state.

OVER-CURRENT. If an over-current condition occurs, the increase in current through the current limit resistor increases the voltage at the cathode of V901 (see Figure 3-9). This increase in voltage is applied across R316 and R317 to the base of Q301 which switches off causing Q302 to switch on. The output of Q302 switches off Q303 which causes Q304 to switch on and Q305 to switch off. When Q305 goes off, the resulting voltage at the cathode of V301 causes the tube to cut off. When V301 stops conducting, K301 and K901 de-energize, and the output voltage is disconnected as described for the over-voltage condition.

AUTOMATIC RESET (OVER-CURRENT). If the OVER LOAD switch is in the AUTO position when the over-current condition occurs the sequence of operations continues as follows: The output voltage being disconnected from the output terminals by K901 removes the over-current condition from the instrument and the voltage at the base of Q301 returns to normal. This causes Q301 to switch on which switches off Q302. Thus, the Schmitt trigger circuit returns to its normal state and the negative going pulse at Q302 causes the flip-flop to return to its normal state. With Q303 again con-

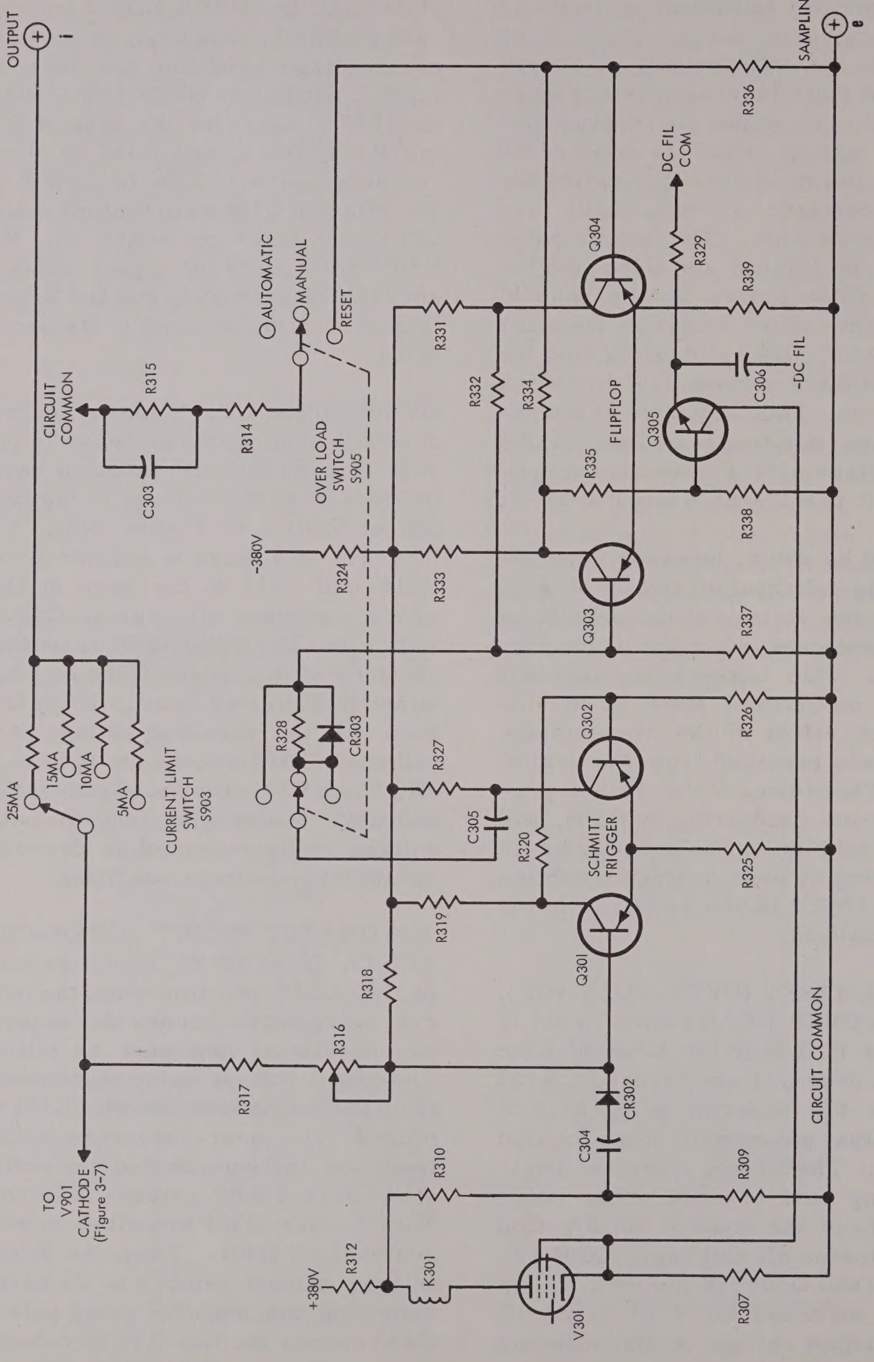


Figure 3-9. Over-Current Protective Circuits, Simplified Schematic Diagram

ducting Q305 conducts causing V301 to start conducting. The relays energize and the output voltage is reconnected to the output terminals. If the over-current condition is again applied to the instrument Q301 switches off as before and this sequence of operations continues as long as the over-current condition exists or until the OVER LOAD switch is set to MAN.

MANUAL RESET (OVER-CURRENT). When the OVER LOAD switch is set to MAN, or if it is in the MAN position when an over-current occurs, CR303 functions as in the case of over-voltage. This prevents the flip-flop from being reset by the Schmitt trigger and in turn keeps Q305 cut off thereby preventing V301 from conducting. The relays remain de-energized and the output voltage remains disconnected from the load. The protective circuits remain in this state until the OVER LOAD switch is set to RESET. When the cause of the over-current condition has been removed, setting the OVER LOAD switch to RESET causes the protective circuits to function in the same manner as for an over-voltage condition. The protective circuits return to the normal state with V301 conducting, the relays energized, and the output voltage applied to the output terminals.

INTERNAL FAULTS. Over-voltage and over-current conditions due to internal faults cause V301 to stop conducting as already described for these conditions. However, it should be noted that when the overload condition is caused internally, disconnection of the output voltage from the output terminals by K901 does not remove the overload condition from the instrument. Therefore, the protective circuits will trip and stay tripped as in the case of manual reset, even when the OVER LOAD switch is in the AUTO position, until the fault has been cleared.

If the DC voltage for the filaments of V201 and V203 in the carrier amplifier fails or if the filament of one of these tubes opens, the small negative voltage at the emitter of Q305 drops to zero and Q305 switches off. When Q305 goes off, the resulting voltage at the cathode of V301 causes the tube to cut off. The protective circuits then remain tripped until the trouble has been cleared.

Section IV
MAINTENANCE

4-1 GENERAL

In addition to preventive maintenance and troubleshooting instructions this section contains the factory calibration procedure. Other information such as disassembly, corrective maintenance, replacement parts, recommended spares, and support data as deemed necessary to maintain the instrument are also included.

4-2 DISASSEMBLY AND PARTS LOCATION

The outer case of the instrument can be removed after releasing the two captive screws at the rear. Removal of the outer case reveals the inner shield enclosure and those items mounted at the rear (see Figure 4-1). The inner enclosure has top and bottom plates secured with screws. When these plates are removed access to the circuit components is available. Figure 4-2 shows the location of the subassemblies and major components viewed from the top and Figure 4-3 shows the view from the bottom.

4-3 PREVENTIVE MAINTENANCE

The instrument requires little routine maintenance other than keeping it clean. Inspect the interior periodically for cleanliness. Whenever it is cleaned internally it is advisable also to visually inspect the instrument.

4-4. GENERAL CLEANING. Inspect and clean the exterior and interior of the instrument initially at three month intervals, and then at intervals determined by experience to minimize the accumulation of dust. If available, forced air pressure is excellent for cleaning, otherwise use a soft brush. However, if the former is used take care not to cause damage by the use of excessive air pressure. It is par-

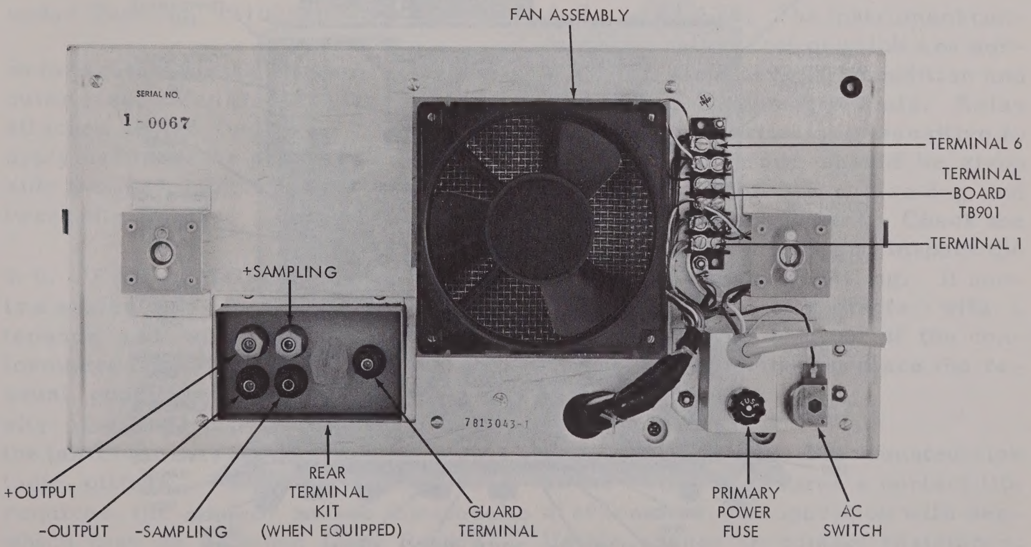


Figure 4-1. Component Location, Rear View

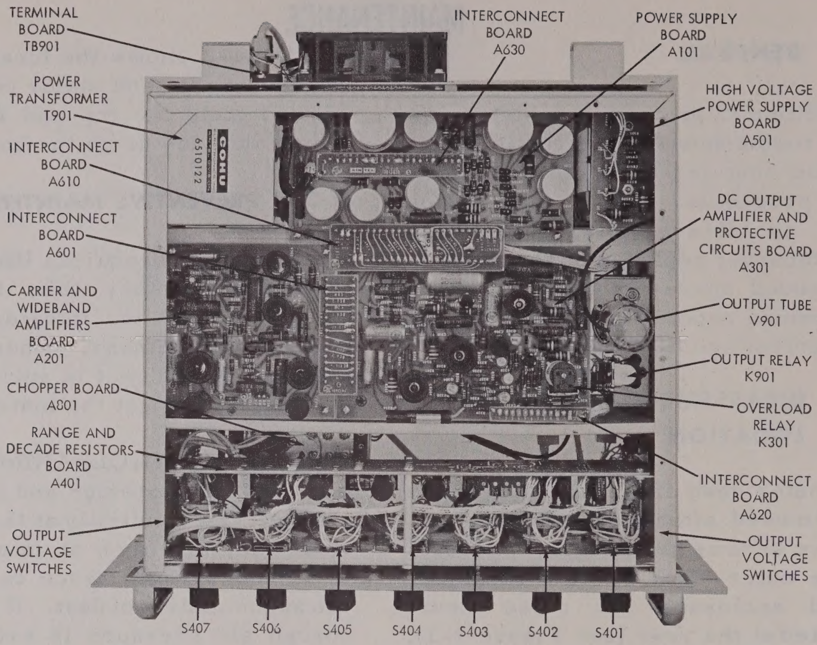


Figure 4-2. Component Location, Top View

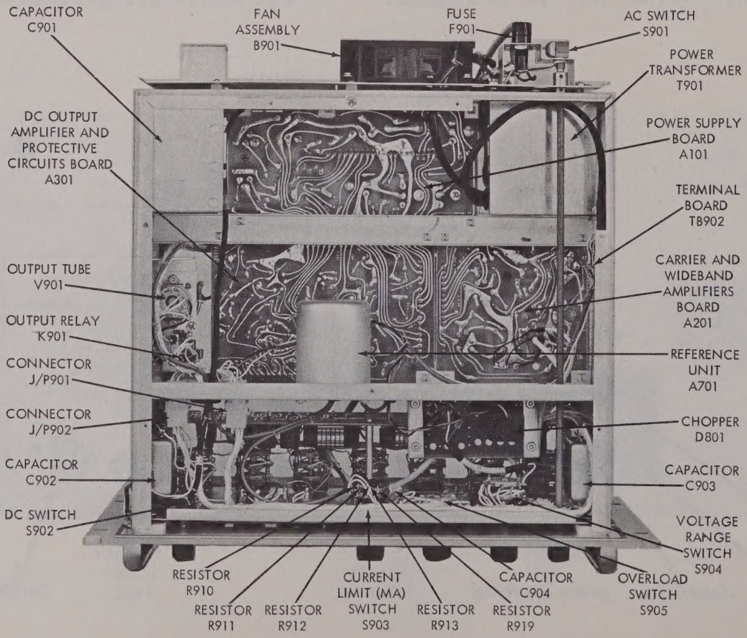


Figure 4-3. Component Location, Bottom View

ticularly important to remove any dust between the instrument enclosures and from the air vents. Cleaning of the front panel terminals should not be overlooked.

4-5. AIR FILTER. The filter element should be cleaned and recoated at intervals determined by environmental conditions. The air filter is secured to the rear of the outer case by four screws. Remove the filter from the outer case and separate the element from its frame. Clean the element in warm soapy water and then rinse thoroughly. After cleaning, the element may be recoated with RP Super Handikoter No. 411, manufactured by Research Products Corporation, 1015 E. Washington Avenue, Madison 10, Wisconsin. The Handikoter contains one pint of compound which is sufficient for several coatings. Additional compound is available from the same source and is packaged in one-gallon, No. 420, and five-gallon, No. 421, units. The one-gallon package is stocked by KIN TEL under Part No. 3310053.

Before returning the instrument to its outer case, clean the air filter screens attached to the two inner shields by applying forced air pressure from inside the instrument. Also, clean between the shields.

4-6. FAN MOTOR. The fan motor is a sealed unit requiring little maintenance and will give reliable performance from two to five years under usual conditions without the necessity of oiling. However, the life of the fan motor may be extended by periodic oilings. The oiling procedure requires the use of an oil injector which may be obtained from Rotron Manufacturing Company, Inc., Hasbrouck Lane, Woodstock, New York. The oiling procedure is as follows:

a. Remove the cap from the end of the oil injector.

b. Place needle of oil injector at the center of circle marked on the gold label.

c. Position the needle at an angle of approximately 45° to the surface of the label and tangent to the perimeter of the circle.

d. Pierce the label and the concealed self-sealing rubber cap located under the label.

e. Insert the needle approximately 1/4 inch.

f. Depress the plunger of the oil injector slowly to allow approximately 1/16 inch of oil to escape. It is better to give a little more oil than not enough, however, do not overfill the well.

4-7. RELAYS. The instrument contains two relays both of which are normally in the energized condition and operate at random intervals. Relay contacts are particularly sensitive to dust and therefore should be given special attention when cleaning and inspecting the instrument. Check the tension of the springs and inspect the contacts for signs of pitting. If necessary, clean the contacts with a contact cleaning tool, or if the contacts are deeply pitted replace the relay.

4-8. SWITCHES. The construction of the switches ensures a contact life of at least 50,000 operation with negligible change in contact resistance. The rotor contacts are double-wiping and self-cleaning and as such require little or no maintenance. The switches are lubricated with a chemically inert lubricant suitable for the normal life of a hand operated switch.

4-9. CHOPPER. In addition to the fan motor the chopper contains the only other continuously moving part in the instrument. Output noise and stability characteristics may be seriously degraded by a malfunctioning chopper. The most valid test of the chopper's performance is to replace it with a known good one. However, more information on the nature and function of choppers is presented in KIN TEL Service Notes, Code No. 13-57A, "Chopper Checkout Procedures for KIN TEL Equipment."

4-10. PERFORMANCE CHECK. If the instrument is in frequent use a performance check is of course not necessary unless faulty operation is suspected. However, when it has not been used for a long time it would be worth while to test the instrument in accordance with the procedure outlined in paragraph 2-9. This procedure checks the performance of the instrument using output voltages up to 10 volts. As an additional check, the instrument performance may be checked at the higher output voltages using any suitable measuring instrument.

4-11 CALIBRATION

Calibration consists of adjusting the instrument for zero volt output, then linearizing the resistance decade and voltage ranges, and finally a scale adjustment for accuracy. Only one standard voltage is required for calibration and this is used when making the final adjustment. The linearization adjustments are made using a variable supply of stable voltage such as another Model 303A, a Model 303, or other instrument of equal stability, otherwise a volt box and a K3 potentiometer may be used. Also required is a galvanometer with a sensitivity comparable to that of the KIN TEL Model 204A. The calibration procedure to be followed is outlined in paragraphs a through e below.

a. Preliminary Procedure

1. Apply power to the instrument and the test equipment.
2. Allow at least one hour for stabilization.
3. Set the CURRENT LIMIT (MA) switch to 5.
4. Set the OVER LOAD switch to AUTO.
5. Set the output voltage dials to indicate zero volts.
6. Slide the instrument out of its case until the adjustment screws of the variable resistors are accessible.

b. Zero Adjustment

1. Connect the instrument to the galvanometer as shown in Figure 4-4.
2. Disconnect the galvanometer leads at the Model 303A terminals and short the disconnected ends of the leads. Zero the galvanometer on its most sensitive scale. Remove the short and re-connect leads.
3. Set the VOLTAGE RANGE switch to 10.

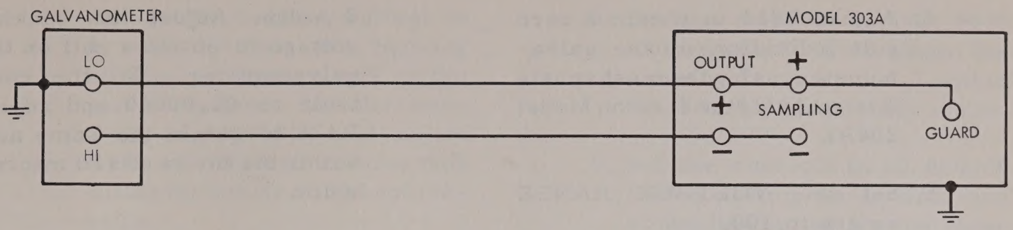


Figure 4-4. Calibration Connections, Zero Volt Output Adjustment

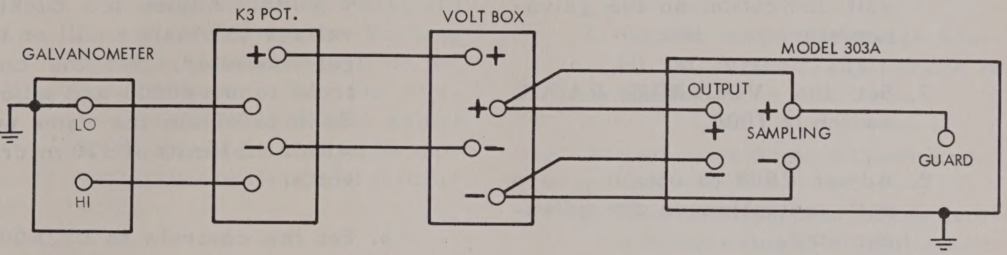


Figure 4-5. Calibration Connections, Linearization

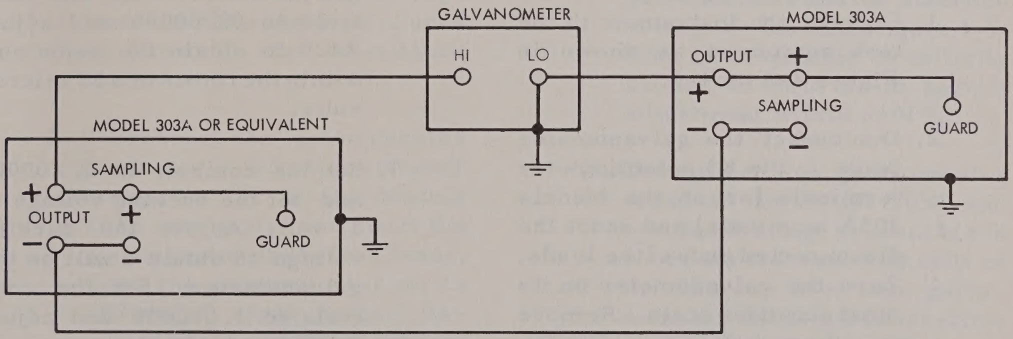


Figure 4-6. Calibration Connections, Linearization

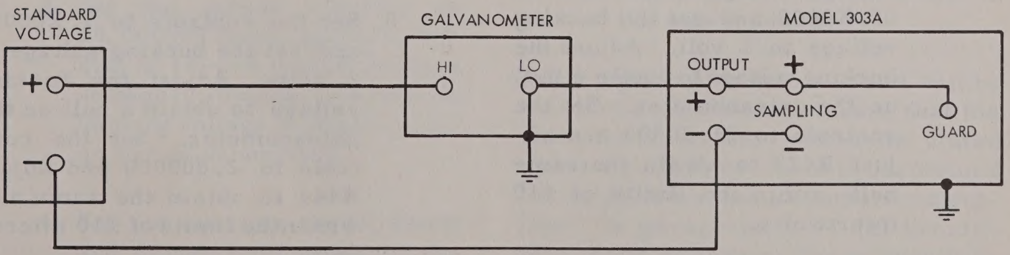


Figure 4-7. Calibration Connections, Scale Adjustment

4. Adjust R814 to obtain a zero volt indication on the galvanometer, using the most sensitive scale (10 µv f. s. on Model 204A).

5. Set the VOLTAGE RANGE switch to 100.

6. Adjust R811 to obtain a zero volt indication on the galvanometer.

7. Set the VOLTAGE RANGE switch to 1000.

8. Adjust R808 to obtain a zero volt indication on the galvanometer.

c. Linearity Adjustment (resistance decade)

1. Connect the instrument to the test equipment as shown in Figure 4-5 or 4-6.

2. Disconnect the galvanometer leads at the K3 potentiometer terminals (or at the Models 303A terminals) and short the disconnected ends of the leads. Zero the galvanometer on its most sensitive scale. Remove the short and re-connect the leads.

3. Set the output controls to 00.X0000 and set the bucking voltage to 1 volt. Adjust the bucking voltage to obtain a null on the galvanometer. Set the controls to 01.00000 and adjust R423 to obtain the same null within the limits of ±10 microvolts.

4. Set the controls to 01.X0000 and set the bucking voltage to 2 volts. Adjust the bucking voltage to obtain a null on the galvanometer. Set the controls to 02.00000 and adjust R425 to obtain the same null within the limits of ±10 microvolts.

5. Set the controls to 03.X0000 and set the bucking voltage to 4 volts. Adjust the bucking voltage to obtain a null on the galvanometer. Set the controls to 04.00000 and adjust R426 to obtain the same null within the limits of ±10 microvolts.

6. Set the controls to 07.X0000 and set the bucking voltage to 8 volts. Adjust the bucking voltage to obtain a null on the galvanometer. Set the controls to 08.00000 and adjust R429 to obtain the same null within the limits of ±10 microvolts.

7. Set the controls to 0.X00000 and set the bucking voltage to 1 volt. Adjust the bucking voltage to obtain a null on the galvanometer. Set the controls to 1.000000 and adjust R430 to obtain the same null within the limits of ±10 microvolts.

8. Set the controls to 1.X00000 and set the bucking voltage to 2 volts. Adjust the bucking voltage to obtain a null on the galvanometer. Set the controls to 2.000000 and adjust R444 to obtain the same null within the limits of ±10 microvolts.

9. Set the controls to 3.X00000

and set the bucking voltage to 4 volts. Adjust the bucking voltage to obtain a null on the galvanometer. Set the controls to 4.000000 and adjust R443 to obtain the same null within the limits of ±10 microvolts.

10. Set the controls to 7.X00000 and set the bucking voltage to 8 volts. Adjust the bucking voltage to obtain a null on the galvanometer. Set the controls to 8.000000 and adjust R442 to obtain the same null within the limits of ±10 microvolts.

d. Linearity Adjustment (voltage ranges)

1. The same set-up is used to linearize the ranges as is used to linearize the resistance decade.

2. Disconnect the galvanometer leads at the K3 potentiometer terminals (or at the Models 303A terminals) and short the disconnected ends of the leads. Zero the galvanometer on its 100 µv full scale range. Remove the short and re-connect the leads.

3. Set the output controls to 10.000000 (note, extreme left dial at 10) and set the bucking voltage to 10 volts. Adjust the bucking voltage to obtain a null on the galvanometer.

4. Set the controls to 0X.00000 and adjust R402 to obtain the same null as in step d.3 within the limits of ±100 microvolts.

5. Set the controls to 00X.0000 and adjust R401 to obtain the same null as in step d.3 within the limits of ±100 microvolts.

6. Set the controls to 10.000000 (same setting as in d.3) and adjust R403 to obtain the same null as in step d.3 within the limits of ±100 microvolts.

7. Repeat steps 3 through 6 until no further adjustment is needed.

e. Accuracy or Scale Adjustment

1. Set the output controls to indicate the value of a local standard voltage.

2. Connect the instrument to the galvanometer and the standard voltage as shown in Figure 4-7. The galvanometer sensitivity should be such as to permit adjustment within .001%.

3. Disconnect the galvanometer leads at the Model 303A and standard voltage terminals and short the disconnected ends of the leads. Zero the galvanometer on its most sensitive scale. Remove the short and re-connect the leads.

4. Adjust R405 to obtain a null on the galvanometer.

A linearity and range re-check can be made when desired to assure that the instrument is still within its stated accuracy. This re-check is performed by using the same procedure as outlined in paragraph 4-11 (a) through (e). Each voltage or range should be within 0.005 percent of the output voltage and range dial setting. If any voltage is not within this limit it is advisable to re-calibrate the instrument.

4-12 TROUBLESHOOTING

WARNING

> Before disassembling the instrument with the power turned on, connect GUARD and + SAMPLING terminals to ground. This ensures that the inner shields are at ground potential. This is an important safety precaution as high voltage exists within the instrument. When troubleshooting with the power on, take care -- not chances.

Familiarity with the theory of operation and the circuits of the instrument is advisable before troubleshooting is attempted. Knowing how the instrument functions, the general area within which a fault exists sometimes can be determined simply by operating the controls and noting the results. Should the need for troubleshooting arise try this method first. Also, try to directly locate the fault by visual inspection and odor. Check for overheated components, discolored resistors, broken wires, cold electron tubes, etc. If these methods fail to give some indication of the cause of the trouble then a systematic check will be necessary.

4-13. TROUBLE LOCALIZATION. Before making a complete systematic check of the instrument circuits it would be as well to investigate the protective circuits first., The protective circuits are of necessity very sensitive and could be tripped by any one of a number of faults, including of course a fault within the protective circuits themselves. If the protective circuits trip, the OVER LOAD indicator will light or flash on and off, depending on the setting of the OVER LOAD switch. If the indicator is flashing, set the OVER LOAD switch to MAN and attempt to reset the protective circuits.

If it is impossible to reset the protective circuits, check for an external overload condition by removing the load. If this is not the cause of the trouble the next step is to determine whether an abnormal condition elsewhere is tripping the protective circuits or whether the protective circuits themselves are faulty.

To determine whether the protective circuits are giving trouble, remove any error voltage that may exist at the summing junction by shorting terminal E6 on the carrier amplifier board to circuit common, setting the output voltage dials to a higher voltage, and then attempting to reset the protective circuits.

CAUTION

> Never short terminal E6 to circuit common for more than a very few seconds as this unbalances the internal loop and the output tube, V901, conducts excessively.

If this causes the OVER LOAD indicator to extinguish, the protective circuits and the carrier amplifier, except the output stage (V204), may be presumed to be functioning correctly.

If the indicator does not extinguish, either the protective circuits or the carrier amplifier or both may be faulty. In this case, check the following: (1) the voltage at the OVER E point on interconnect board A601 should be +1.1 volts (2) the voltage at the + and - DC FIL points on interconnect board A610 should be 12 volts.

If the voltage at the OVER E point is correct it can be presumed that the carrier amplifier, except the output stage (V204), is functioning properly and that a faulty condition within the protective circuits is preventing V301 from conducting. If the voltage at the DC FIL points is correct, either the trouble lies with the protective circuits, or the filament of V201 or V203 in the carrier amplifier is open circuit thereby removing the Q305 emitter bias voltage developed across R329 in the protective circuits (see Figure 4-8). If the voltage at the DC FIL points is very low or absent check the appropriate input and output of power supply A101.

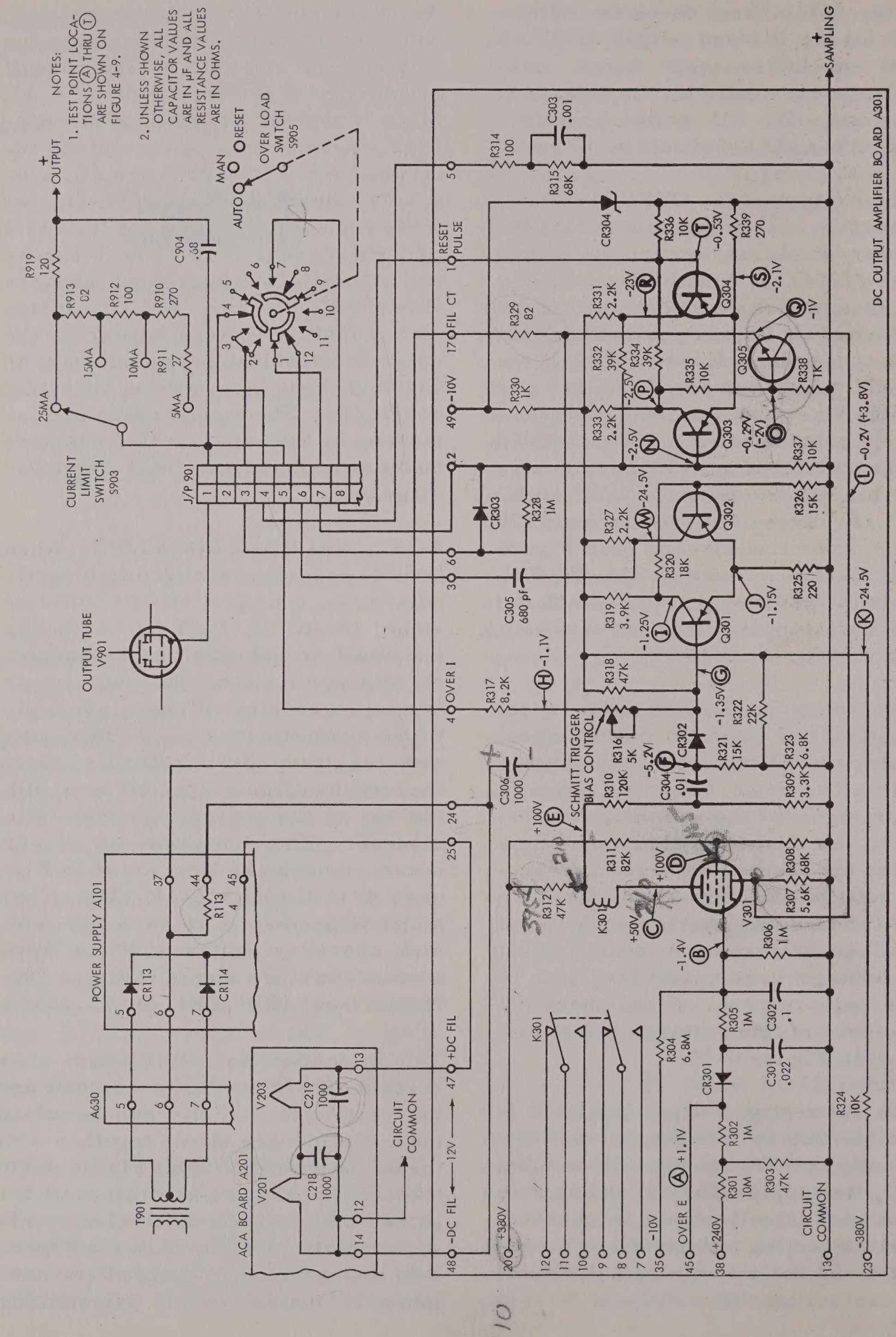
If the protective circuits can be reset (OVER LOAD indicator extinguishes) with terminal E6 momentarily shorted to circuit common, this could mean an error signal at the summing junction due to the direct-coupled output amplifier not responding to the correcting voltage. In this case, measure the AC correcting voltage at the point DCA2 on interconnect board A601; this voltage is normally less than 10 volts peak-to-peak. Also, check the waveform of this voltage against that shown in Figure 4-10.

If the correcting voltage is high it is possible that the DC output amplifier is faulty, otherwise the output tube, V901, its supply voltages, and closely associated circuits should be checked. If the correcting voltage is low or absent check the output stage, V204, of the carrier amplifier.

Any fault not located by association with the protective circuits can be localized with the aid of the overall schematic diagram, Figure 4-22. Make a systematic check of the voltages shown in this figure and the individual circuit board schematic diagrams Figures 4-17 through 4-21, and trace signals to localize the fault to a particular area. Most of these checks can be made at the interconnect boards shown in Figure 4-9. The waveforms shown in Figure 4-10 appear at the points indicated by circled numbers in Figure 4-9 and show normal operating conditions. These points also are indicated by the same circled numbers on the overall and individual schematic diagrams.

4-14. TROUBLE LOCATING. When trouble has been localized to a particular area, such as a circuit board or stage, locate the fault by employing the usual troubleshooting techniques of tracing signals, checking waveforms, measuring voltages, and testing components; no special techniques are required. Systematically check the circuits of the suspected area with the aid of the appropriate schematic diagram. The locations of circuit board components are shown in Figures 4-11 through 4-16. The schematic diagrams are marked with normal operating voltages which were measured using a meter having a 100-Mohm input (KIN TEL Model 203A).

The DC output amplifier board also contains the demodulator circuit and the protective circuits and therefore these circuits are shown together with the DC output amplifier in Figure 4-20. However, the protective circuits together with certain other closely associated circuits are shown in Figure 4-8; this schematic diagram is particularly useful when determining



NOTES:
1. TEST POINT LOCATIONS Ⓐ THRU Ⓣ ARE SHOWN ON FIGURE 4-9.
2. UNLESS SHOWN OTHERWISE, ALL CAPACITOR VALUES ARE IN µF AND ALL RESISTANCE VALUES ARE IN OHMS.

Figure 4-8. Protective Circuits

410

whether a fault elsewhere is tripping the protective circuits or whether the protective circuits are faulty, as well as for troubleshooting the protective circuits.

The voltages at the points indicated by circled letters in Figure 4-8 are normal operating voltages, that is, when the protective circuits are not tripped. At two of these points, one at the base of Q305 and one at the collector of Q305 and the cathode of V301, the voltages when the protective circuits are in the tripped condition are shown in parentheses. Another point to be noted is that the -10 volts at terminal 49 is derived from the -380 volts at terminal 23. The -10 volts, which is stabilized by Zener diode CR304, is applied to the DC output amplifier board to provide bias voltage for the control grid of V301. The -10 volts also is applied to the carrier and wideband amplifiers board where it is dropped to -6 volts. The -6 volts is divided to provide the bias voltages for the control grids of V201B, V203, and V204 in the carrier amplifier, and V201A in the wideband amplifier. This -6 volts also is applied via terminal E12 to the zero volt adjustment resistors on the chopper board.

4-15 INTERNAL ADJUSTMENTS

Two internal adjustments, the Schmitt trigger circuit bias level and the DC balance, should be made when certain repairs have been made to the instrument circuits. The trigger circuit adjustment can be made through a hole in the inner enclosure after the outer case has been removed. Removal of the top plate of the inner enclosure is necessary before the DC balance can be adjusted.

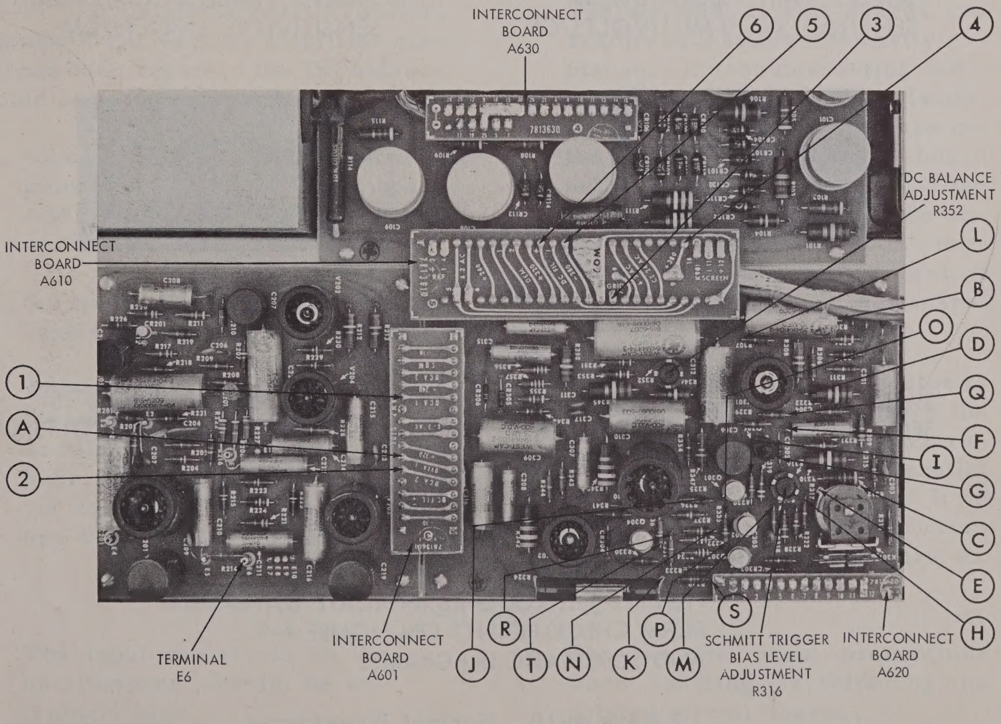
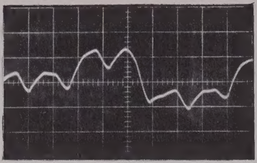
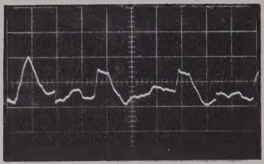


Figure 4-9. Check Point Locations



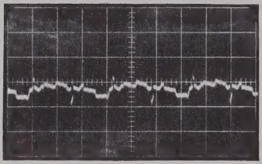
①
DCA1

SWEEP: 5 MILLISECONDS/CM
SENSITIVITY: 50 MILLIVOLTS/CM



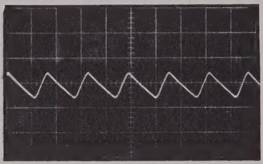
②
DCA2

SWEEP: 5 MILLISECONDS/CM
SENSITIVITY: 5 VOLTS/CM



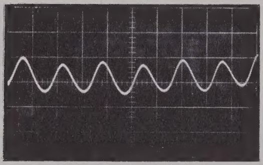
③
V901 GRID

SWEEP: 5 MILLISECONDS/CM
SENSITIVITY: 50 MILLIVOLTS/CM



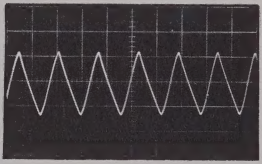
④
+380V

SWEEP: 5 MILLISECONDS/CM
SENSITIVITY: 5 VOLTS/CM



⑤
-380V

SWEEP: 5 MILLISECONDS/CM
SENSITIVITY: 100 MILLIVOLTS/CM



⑥
+DC FIL

SWEEP: 5 MILLISECONDS/CM
SENSITIVITY: 500 MILLIVOLTS/CM

NOTE

FIGURES①THROUGH⑥INDICATE WAVEFORM CHECK POINTS ON FIGURE 4-9 AND SCHEMATIC DIAGRAMS.

Figure 4-10. Normal Waveforms

4-16. SCHMITT TRIGGER BIAS LEVEL ADJUSTMENT. Whenever the protective circuits have been repaired the level of bias for the Schmitt trigger circuit should be adjusted as follows:

a. Set the OVER LOAD switch to AUTO.

b. Set the CURRENT LIMIT (MA) switch to 25.

c. Connect a 25 MA load to the instrument.

d. Adjust R316 (see Figure 4-9 for location) until the OVER LOAD indicator just starts to flash on and off.

e. Check adjustment with 15, 10, and 5 MA loads.

4-17. DC BALANCE ADJUSTMENT. Whenever the carrier amplifier circuit has been repaired the DC balance should be adjusted as follows:

a. Connect an oscilloscope between point DCA2 on interconnect board A601 (see Figure 4-9 for location) and circuit common.

b. Set the oscilloscope to 5 volts per centimeter sensitivity.

c. Adjust R352 (see Figure 4-9 for location) to obtain a null on the oscilloscope. The signal should have a peak-to-peak voltage of not more than 10 volts (see Figure 4-10 for waveform).

NOTE

The input resistance to the oscilloscope should be extremely high.

4-18 CORRECTIVE MAINTENANCE

When troubleshooting or performing corrective maintenance the following points should be borne in mind:

a. It is recommended that no attempt be made to troubleshoot the reference unit. If it gives trouble it should be replaced as an assembly as special treatment is necessary to correct a faulty reference unit.

b. The chopper and the transistors are of the plug-in type and therefore easily replaceable. The most valid performance test of these components is to replace them with components known to be good. Do not replace chopper with instrument operating.

c. The printed circuit boards are readily accessible and easily replaced. If troubleshooting indicates a circuit board to be faulty, and tubes or transistors are not the cause, replacing the board with a spare will usually be the quickest way to restore the instrument to service. Don't forget to repair the faulty board; it may be now the one and only spare.

d. When the value of a resistor is suspected of being low, check the schematic diagram for other resistance connected in parallel with it before replacing. If in doubt, remove the resistor from the circuit and re-measure its value.

e. Observe the usual precautions when handling or soldering the printed circuit boards.

4-19 REPLACEMENT PARTS AND RECOMMENDED SPARES

A list of replacement parts, arranged alphabetically and numerically according to reference designation, is contained in Table 4-1, and lists of recommended spares which are available as kits are contained in Table 4-2.

NOTE

If the type, value, etc, of a component to be replaced is different from that given in Table 4-1, make the replacement using the component listed.

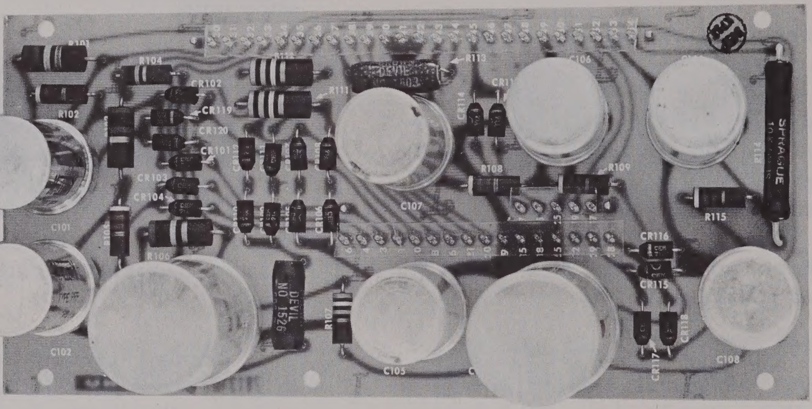


Figure 4-11. Power Supply Board, Component Locations

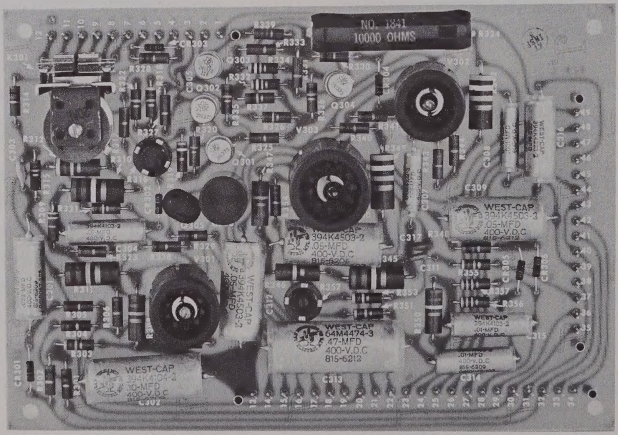


Figure 4-12. DC Output Amplifier and Protective Circuits Board, Component Locations

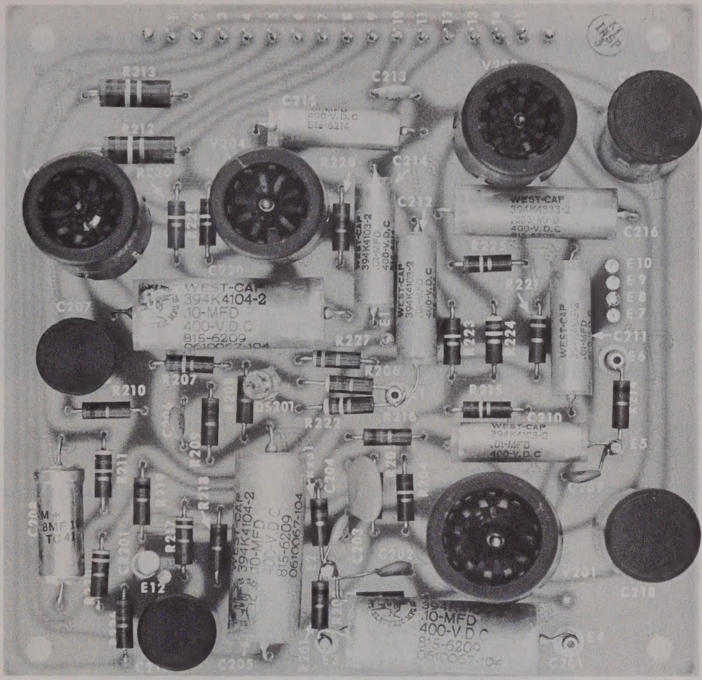


Figure 4-13. Carrier and Wideband Amplifiers Board, Component Locations

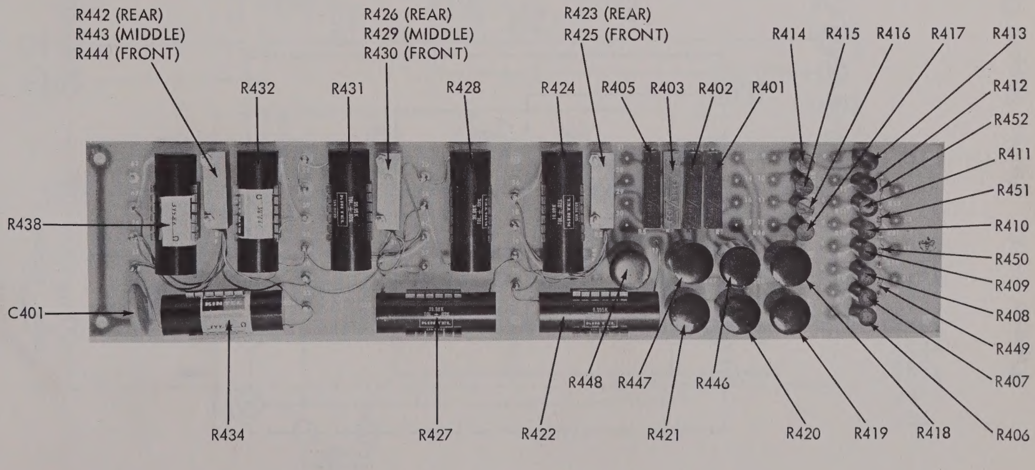


Figure 4-14. Resistance Decade Board, Component Locations

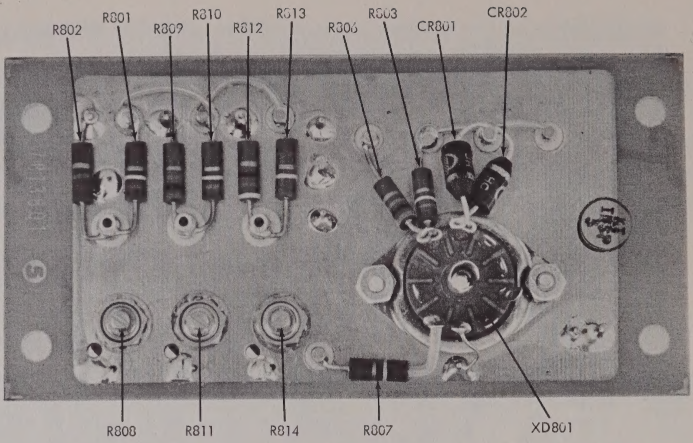


Figure 4-15. Chopper Board, Component Locations

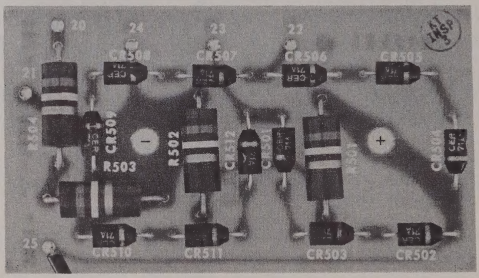


Figure 4-16. High Voltage Power Supply, Component Locations

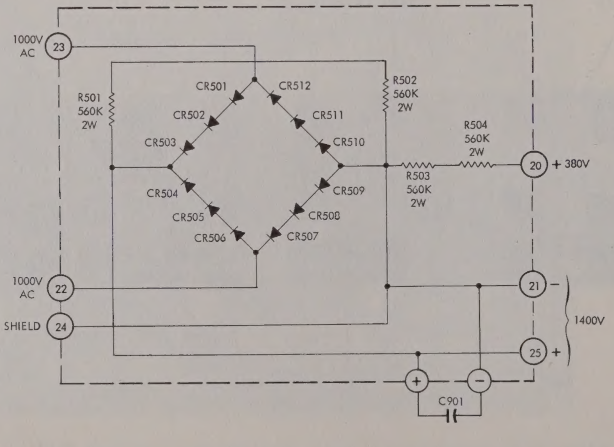
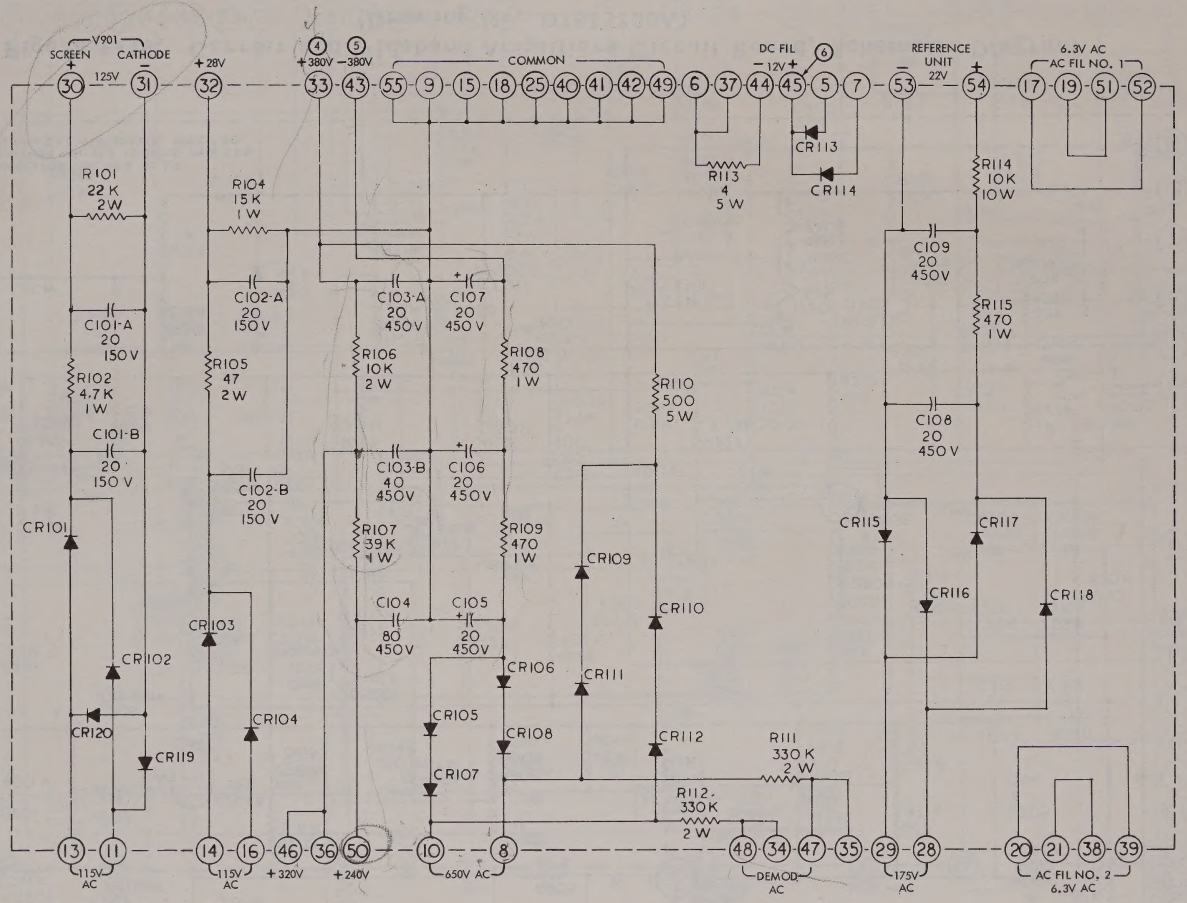
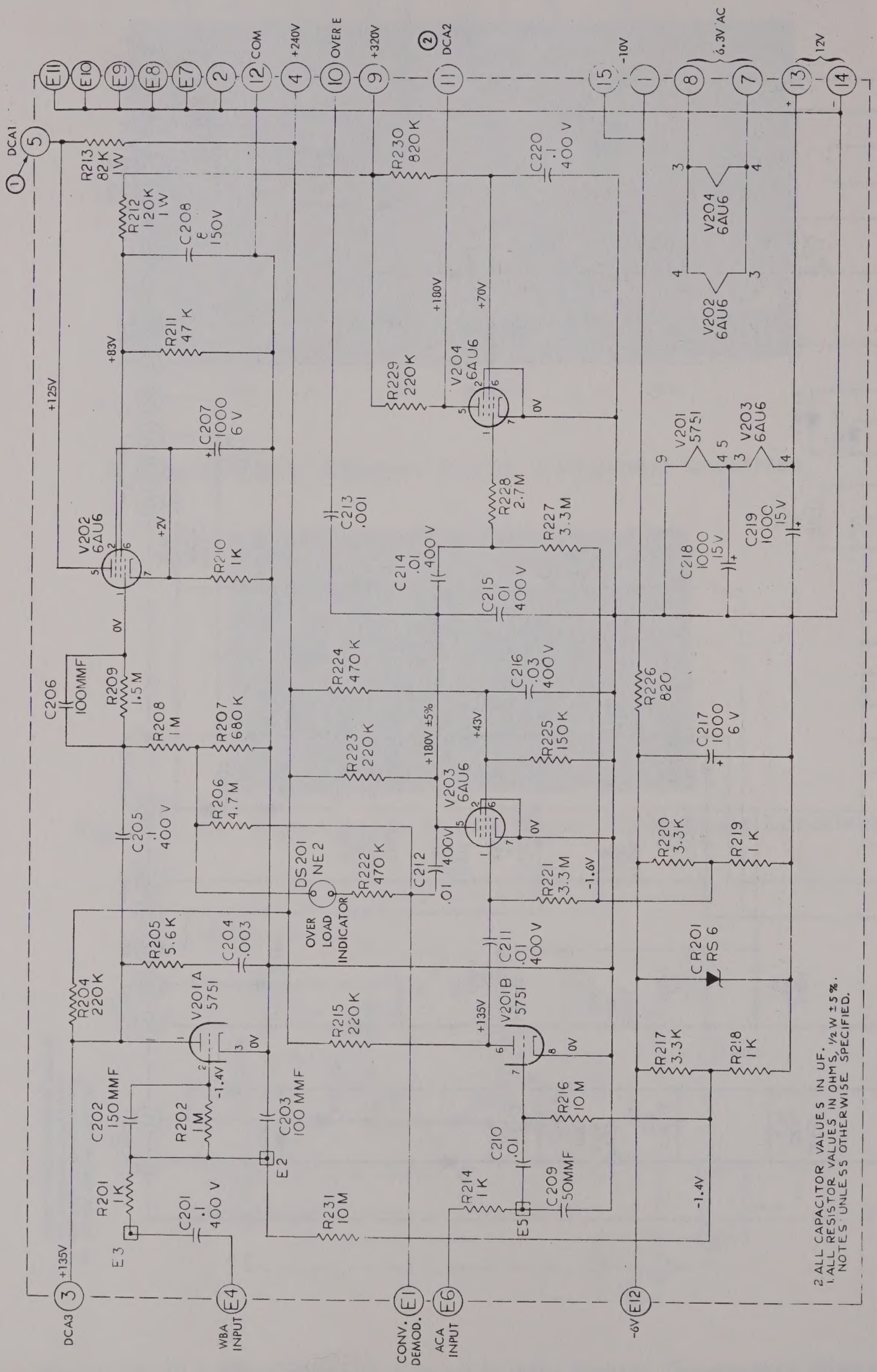


Figure 4-17. High Voltage Power Supply Board, Schematic Diagram (Drawing No. C7813500B)



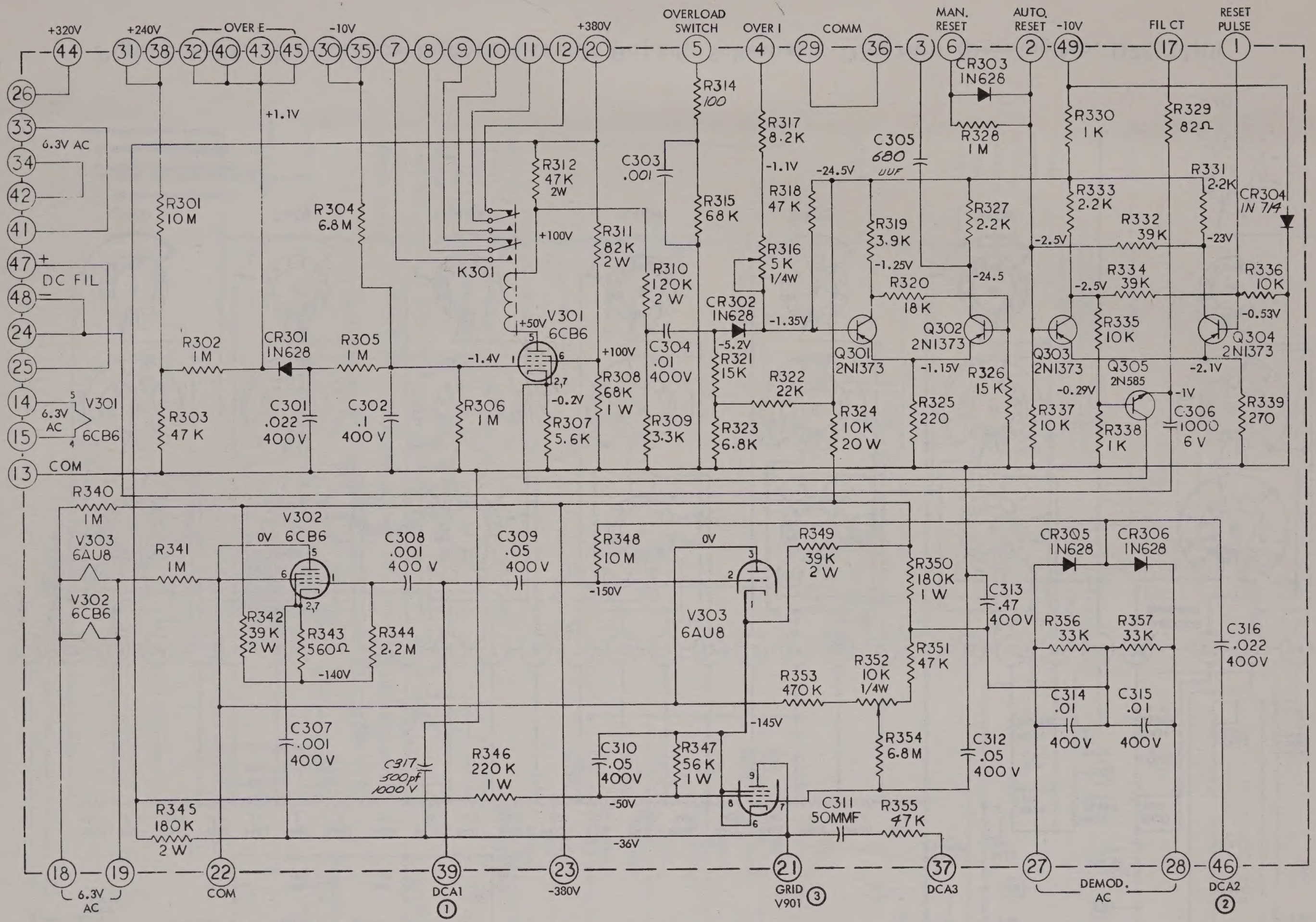
3. ALL RESISTORS IN OHMS ±5%.
2. ALL CAPACITOR VALUES IN µF.
1. ALL DIODES ARE TYPE CER71A.
NOTES: UNLESS OTHERWISE SPECIFIED

Figure 4-18. Power Supply Circuit Board, Schematic Diagram (Drawing No. D7813100C)



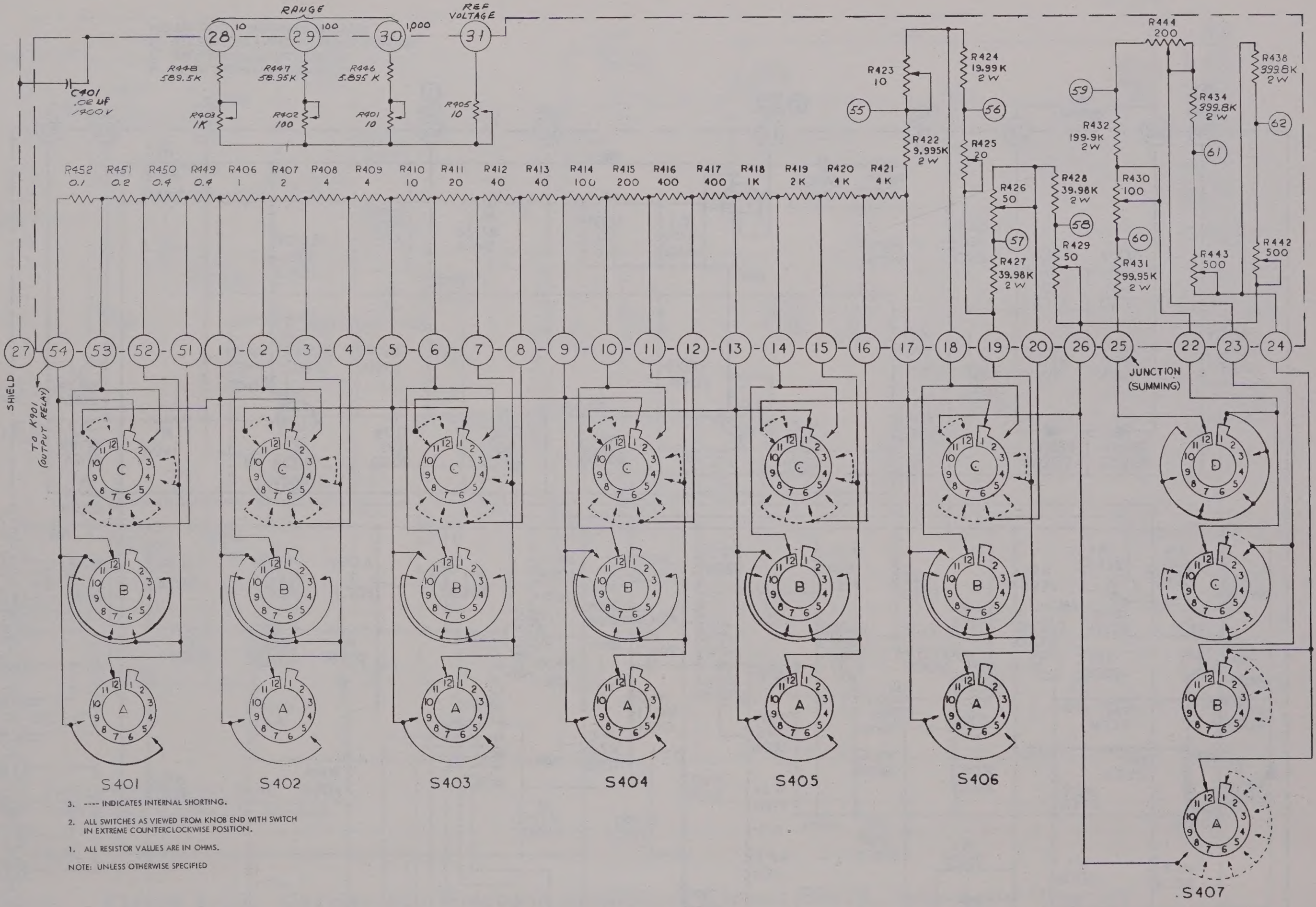
NOTES: UNLESS OTHERWISE SPECIFIED.
1. ALL RESISTOR VALUES IN OHMS, 1/2 W ±5%.
2. ALL CAPACITOR VALUES IN UF.

Figure 4-19. Carrier and Wideband Amplifiers Circuit Board, Schematic Diagram (Drawing No. D7813200A)



3. RELAY SHOWN DE-ENERGIZED.
2. ALL CAPACITOR VALUES IN μF.
1. ALL RESISTOR VALUES IN OHMS, 1/2W ±5%.
NOTES: UNLESS OTHERWISE SPECIFIED

Figure 4-20. DC Output Amplifier Circuit Board, Schematic Diagram (Drawing No. 7813300G)



3. ---- INDICATES INTERNAL SHORTING.

2. ALL SWITCHES AS VIEWED FROM KNOB END WITH SWITCH IN EXTREME COUNTERCLOCKWISE POSITION.

1. ALL RESISTOR VALUES ARE IN OHMS.

NOTE: UNLESS OTHERWISE SPECIFIED

Figure 4-21. Resistance Decade Circuit Board, Schematic Diagram (Drawing No. D7813410)

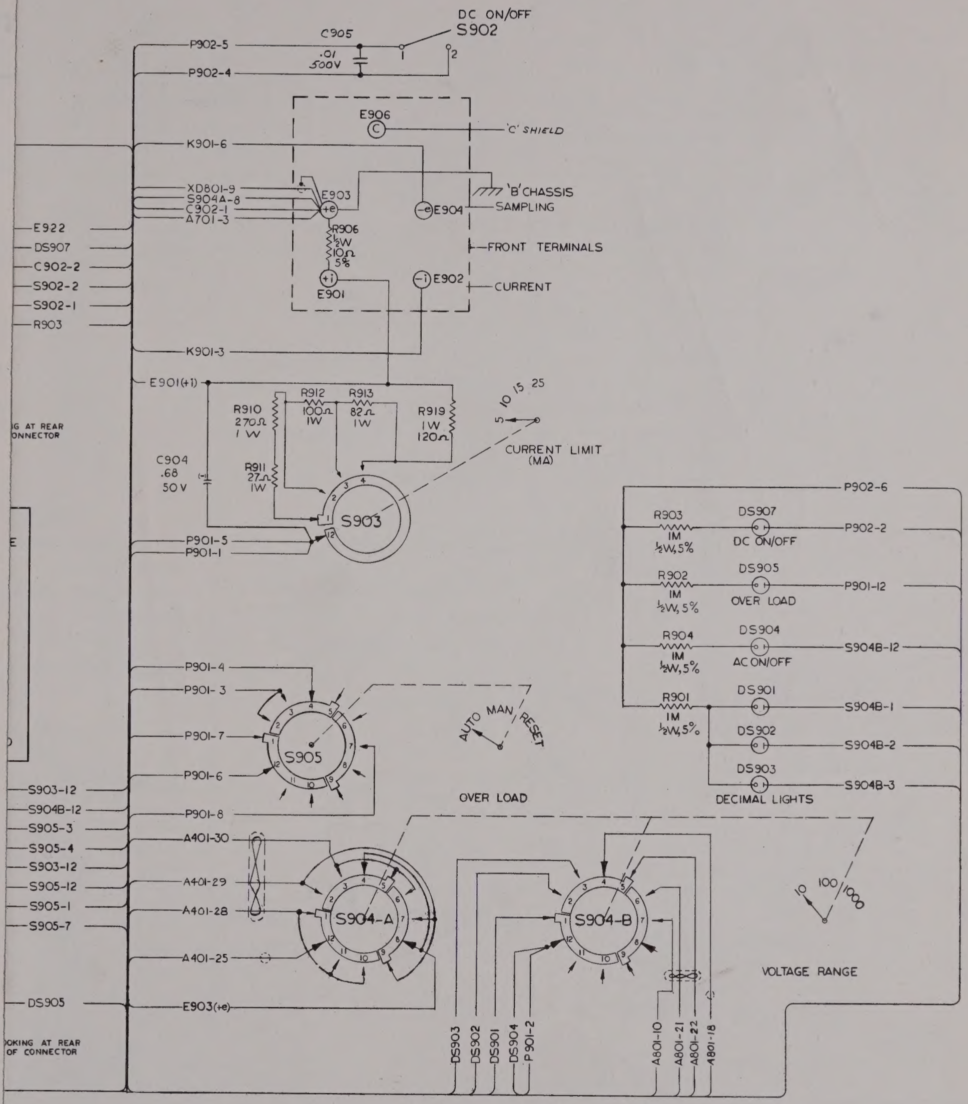
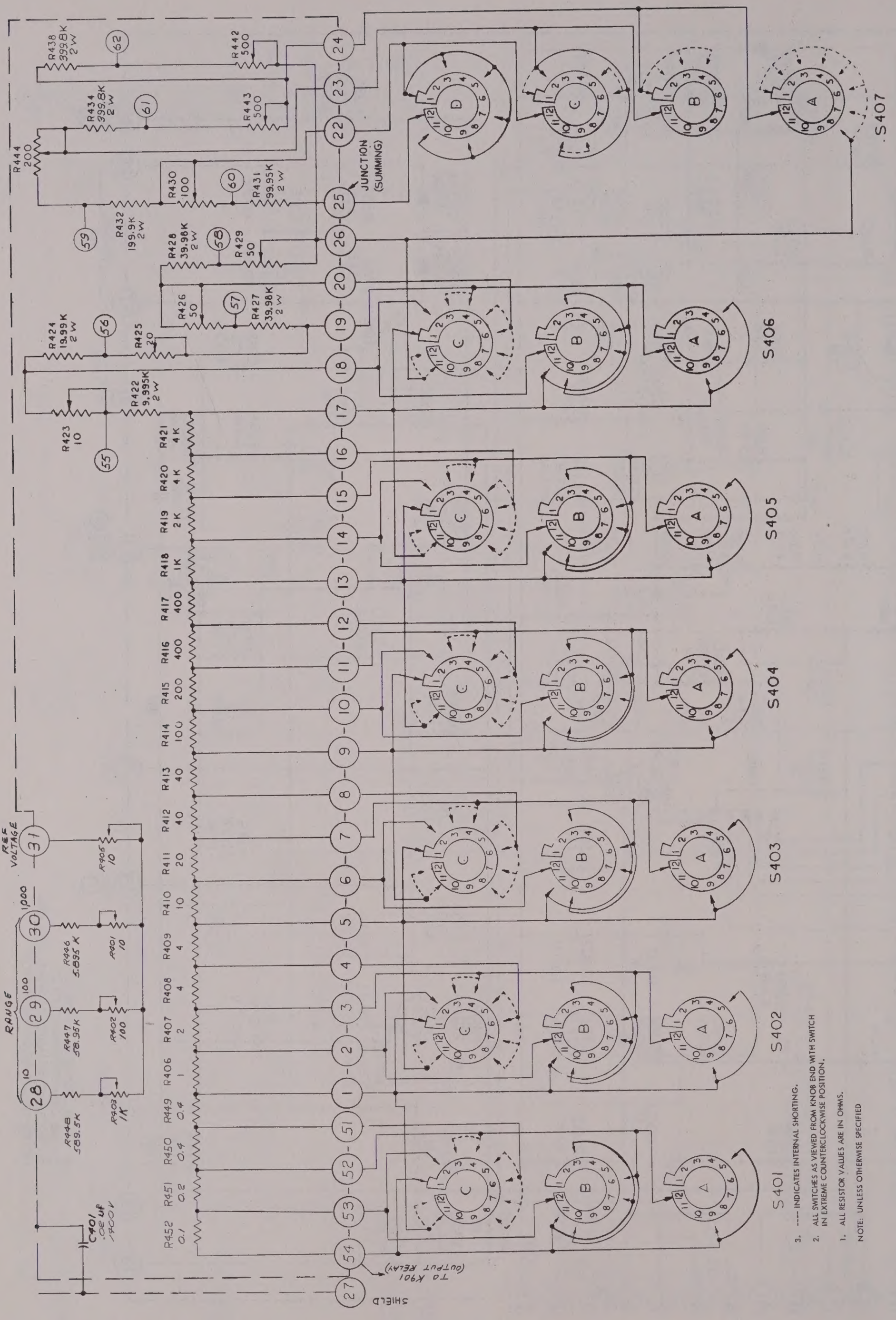


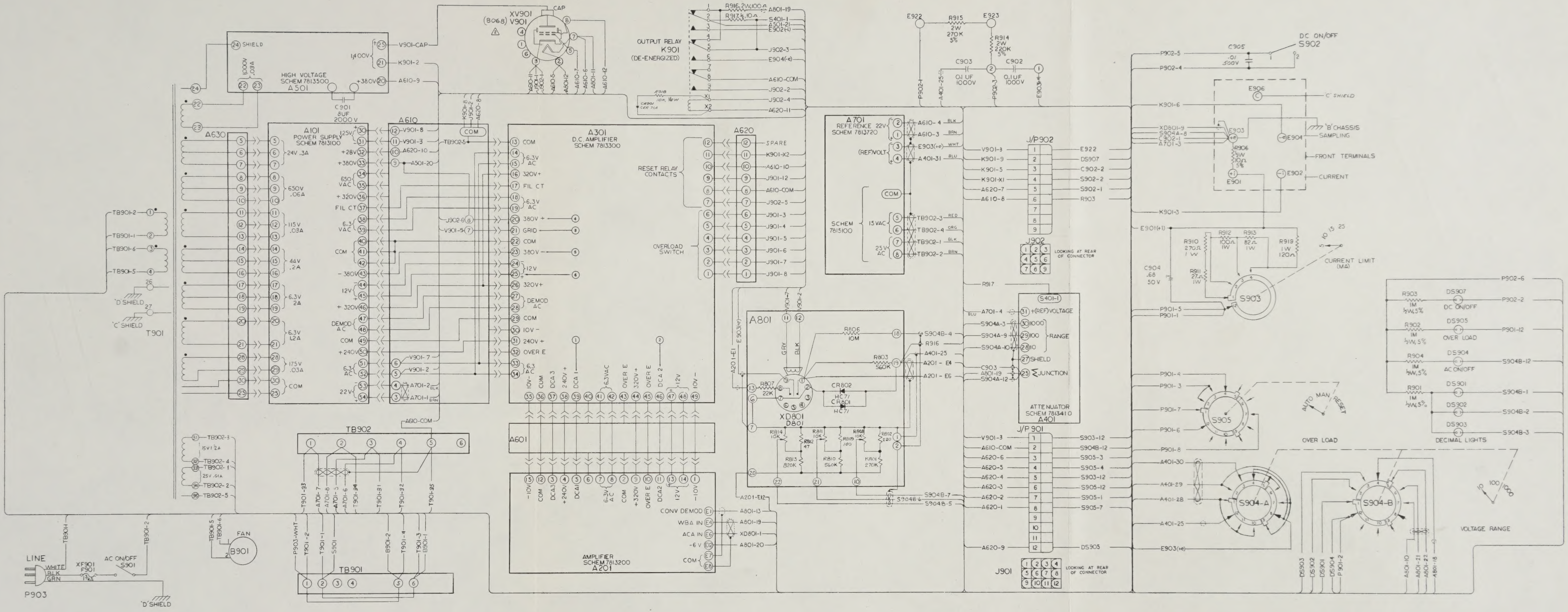
Figure 4-22. Model 303A, Overall Schematic Diagram
(Drawing No. J7813902D)

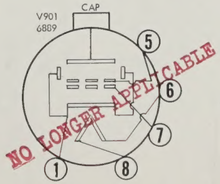


NOTE: UNLESS OTHERWISE SPECIFIED

1. ALL RESISTOR VALUES ARE IN OHMS.
2. ALL SWITCHES AS VIEWED FROM KNOB END WITH SWITCH IN EXTREME COUNTERCLOCKWISE POSITION.
3. ---- INDICATES INTERNAL SHORTING.

Figure 4-21. Resistance Decade Circuit Board, Schematic Diagram (Drawing No. D7313410)





NO LONGER APPLICABLE

2. SOME INSTRUMENTS ARE EQUIPPED WITH TUBE TYPE 6889. THE ELECTRODES OF THIS TUBE ARE CONNECTED TO THE PINS AS NUMBERED AND SHOWN ADJACENT TO THIS NOTE.

NO LONGER APPLICABLE

1. WAVEFORMS FOR VOLTAGES ① THRU ⑥ ARE SHOWN IN FIGURE 4-10.

NOTES: UNLESS OTHERWISE SPECIFIED

Figure 4-22. Model 303A, Overall Schematic Diagram
(Drawing No. J7813902D)

Table 4-1. List of Replacement Parts

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
A101	ASSEMBLY, PRINTED CIRCUIT, Power Supply	7813101-001
A201	ASSEMBLY, PRINTED CIRCUIT, Carrier and Wideband Amplifiers	7813201-001
A301	ASSEMBLY, PRINTED CIRCUIT, DC Output Amplifier	7813301-001
A401	ASSEMBLY, PRINTED CIRCUIT, Range and Decade Resistors	7816411-001
A501	ASSEMBLY, PRINTED CIRCUIT, High Voltage Power Supply	7813501-001
A601	ASSEMBLY, PRINTED CIRCUIT, Amplifier Board Connector	7813601-001
A610	ASSEMBLY, PRINTED CIRCUIT, Power Supply Board Connector	7813610-001
A620	ASSEMBLY, PRINTED CIRCUIT, Reset Board Connector	7813620-001
A630	ASSEMBLY, PRINTED CIRCUIT, Power Transformer Board Connector	7813630-001
A701	REFERENCE UNIT	7813091-001
A801	ASSEMBLY, PRINTED CIRCUIT, Chopper	7813801-001
B901	FAN, ELECTRICAL, 100 cfm, 115-120 VAC, 60 CPS	3110023-002
C101	CAPACITOR, FIXED, ELECTROLYTIC, 20/20 μf, 150 VDC	0510059
C102	CAPACITOR, FIXED, ELECTROLYTIC, 20/20 μf, 150 VDC	0510059
C103	CAPACITOR, FIXED, ELECTROLYTIC, 20/40 μf, 450 VDC	0510121-006

Table 4-1. List of Replacement Parts (Contd).

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
C104	CAPACITOR, FIXED, ELECTROLYTIC, 80 µf, 450 VDC	0510121-005
C105	CAPACITOR, FIXED, ELECTROLYTIC, 20 µf, 450 VDC	0510122-002
C106	CAPACITOR, FIXED, ELECTROLYTIC, 20 µf, 450 VDC	0510122-002
C107	CAPACITOR, FIXED, ELECTROLYTIC, 20 µf, 450 VDC	0510122-002
C108	CAPACITOR, FIXED, ELECTROLYTIC, 20 µf, 450 VDC	0510122-002
C109	CAPACITOR, FIXED, ELECTROLYTIC, 20 µf, 450 VDC	0510122-002
C201	CAPACITOR, FIXED, FILM, 0.1 µf, 400 VDC	0610067-104
C202	CAPACITOR, FIXED, CERAMIC DISC, 150 pf, 1000 VDC	0401025
C203	CAPACITOR, FIXED, CERAMIC DISC, 100 pf, 1000 VDC	0401022
C204	CAPACITOR, FIXED, CERAMIC DISC, 0.0033 µf, 1000 VDC	0401051
C205	CAPACITOR, FIXED, MYLAR, 0.1 µf, 400 VDC	0610018-027
C206	CAPACITOR, FIXED, CERAMIC DISC, 100 pf, 1000 VDC	0401022
C207	CAPACITOR, FIXED, ELECTROLYTIC, 1000 µf, 6 VDC	0510089-020

Table 4-1. List of Replacement Parts (Contd).

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
C208	CAPACITOR, FIXED, ELECTROLYTIC, 8 μf, 150 VDC	0510107-001
C209	CAPACITOR, FIXED, CERAMIC DISC, 50 pf, 1000 VDC	0401016
C210	CAPACITOR, FIXED, FILM, 0.01 μf, 400 VDC	0610067-103
C211	CAPACITOR, FIXED, MYLAR, 0.01 μf, 400 VDC	0610018-015
C212	CAPACITOR, FIXED, MYLAR, 0.01 μf, 400 VDC	0610018-015
C213	CAPACITOR, FIXED, CERAMIC DISC, 0.001 μf, 500 VDC	0401046
C214	CAPACITOR, FIXED, MYLAR, 0.01 μf, 400 VDC	0610018-015
C215	CAPACITOR, FIXED, MYLAR, 0.01 μf, 400 VDC	0610018-015
C216	CAPACITOR, FIXED, MYLAR, 0.033 μf, 400 VDC	0610018-021
C217	CAPACITOR, FIXED, ELECTROLYTIC, 1000 μf, 6 VDC	0510089-020
C218	CAPACITOR, FIXED, ELECTROLYTIC, 1000 μf, 15 VDC	0510092-020
C219	CAPACITOR, FIXED, ELECTROLYTIC, 1000 μf, 15 VDC	0510092-020
C220	CAPACITOR, FIXED, MYLAR, 0.01 μf, 400 VDC	0610018-027

Table 4-1. List of Replacement Parts (Contd).

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
C301	CAPACITOR, FIXED, MYLAR, 0.022 µf, 400 VDC	0610018-019
C302	CAPACITOR, FIXED, MYLAR, 0.1 µf, 400 VDC	0610018-027
C303	CAPACITOR, FIXED, CERAMIC DISC, 0.001 µf, 500 VDC	0401046
C304	CAPACITOR, FIXED, MYLAR, 0.01 µf, 400 VDC	0610018-015
C305	CAPACITOR, FIXED, CERAMIC DISC, 680 pf, 1000 VDC	0401042
C306	CAPACITOR, FIXED, ELECTROLYTIC, 1000 µf, 6 VDC	0510089-020
C307	CAPACITOR, FIXED, FILM, 0.001 µf, 400 VDC	0610098-449
C308	CAPACITOR, FIXED, FILM, 0.001 µf, 400 VDC	0610098-449
C309	CAPACITOR, FIXED, FILM, 0.05 µf, 400 VDC	0610067-503
C310	CAPACITOR, FIXED, MYLAR, 0.05 µf, 400 VDC	0610018-023
C311	CAPACITOR, FIXED, CERAMIC DISC, 50 pf, 1000 VDC	0401016
C312	CAPACITOR, FIXED, FILM, 0.05 µf, 400 VDC	0610067-503
C313	CAPACITOR, FIXED, FILM, 0.47 µf, 400 VDC	0610098-448

Table 4-1. List of Replacement Parts (Contd).

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
C314	CAPACITOR, FIXED, MYLAR, 0.01 μf, 400 VDC	0610018-015
C315	CAPACITOR, FIXED, MYLAR, 0.01 μf, 400 VDC	0610018-015
C316	CAPACITOR, FIXED, FILM, 0.022 μf, 400 VDC	0610067-223
C317	CAPACITOR, FIXED, CERAMIC DISC, 500 pf, 1000 VDC	0401039
C318	CAPACITOR, FIXED, CERAMIC DISC, 0.01 μf, 500 VDC	0401056
C401	CAPACITOR, FIXED, CERAMIC DISC, 0.02 μf, 1400 VDC	0410013-001
C901	CAPACITOR, FIXED, PLASTIC, 8 μf, 2000 VDC	0810013-001
C902	CAPACITOR, FIXED, POLYSTYRENE, 0.1 μf, 1000 VDC	0610108-002
C903	CAPACITOR, FIXED, POLYSTYRENE, 0.1 μf, 1000 VDC	0610108-002
C904	CAPACITOR, FIXED, METALLIZED PAPER, 0.68 μf, 50 VDC	0610099-006
C905	CAPACITOR, FIXED, CERAMIC DISC 0.01 μf, 500 VDC	0401056
CR101	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR102	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR103	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001

Table 4-1. List of Replacement Parts (Contd).

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
CR104	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR105	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR106	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR107	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR108	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR109	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR110	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR111	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR112	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR113	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR114	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR115	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR116	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001

Table 4-1. List of Replacement Parts (Contd).

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
CR117	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR118	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR119	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR120	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR201	SEMICONDUCTOR DEVICE, DIODE, Type RS-6	3510022-004
CR301	SEMICONDUCTOR DEVICE, DIODE, Type 1N628	3510004
CR302	SEMICONDUCTOR DEVICE, DIODE, Type 1N628	3510004
CR303	SEMICONDUCTOR DEVICE, DIODE, Type 1N628	3510004
CR304	SEMICONDUCTOR DEVICE, DIODE, Type 1N714	3510042-012
CR305	SEMICONDUCTOR DEVICE, DIODE, Type 1N628	3510004
CR306	SEMICONDUCTOR DEVICE, DIODE, Type 1N628	3510004
CR501	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR502	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001

Table 4-1. List of Replacement Parts (Contd)

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
CR503	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR504	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR505	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR506	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR507	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR508	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR509	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR510	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR511	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR512	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001
CR801	SEMICONDUCTOR DEVICE, DIODE, Type HC71	3510053-005
CR802	SEMICONDUCTOR DEVICE, DIODE, Type HC71	3510053-005
CR901	SEMICONDUCTOR DEVICE, DIODE, Type CER71A	3510053-001

Table 4-1. List of Replacement Parts (Contd)

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
D801	CHOPPER, ELECTRO-MECHANICAL, SPDT, 6.3 VAC, 60 CPS, 86Ω	6310018-001
DS201	LAMP, NEON, INDICATOR, Type NE-2	1704151
DS901	LAMP, NEON, INDICATOR, Type NE-2 in assembly	1710152-002
DS902	LAMP, NEON, INDICATOR, Type NE-2 in assembly	1710152-002
DS903	LAMP, NEON, INDICATOR, Type NE-2 in assembly	1710152-002
DS904	LAMP, NEON, INDICATOR, Type NE-2 in assembly	1710152-002
DS905	LAMP, NEON, INDICATOR, Type NE-2 in assembly	1710152-002
DS907	LAMP, NEON, INDICATOR, Type NE-2 in assembly	1710152-002
F901	FUSE, CARTRIDGE, 1.5 amp, SLO-BLO	1710040-122
J901	CONNECTOR, ELECTRICAL, RECEPTACLE, 12-contact	1310106-004
J902	CONNECTOR, ELECTRICAL, RECEPTACLE, 9-contact	1310106-003
K301	RELAY, ARMATURE 2 form C closures, 10K	3710034-001
K901	RELAY, ARMATURE, 3 form C closures, 28 VDC, 500Ω	3710006-008

Table 4-1. List of Replacement Parts (Contd)

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
P901	CONNECTOR, ELECTRICAL, PLUG, 12-contact	1310105-004
P902	CONNECTOR, ELECTRICAL, PLUG, 9-contact	1310105-003
Q301	TRANSISTOR, Type 2N1373	7210039-005
Q302	TRANSISTOR, Type 2N1373	7210039-005
Q303	TRANSISTOR, Type 2N1373	7210039-005
Q304	TRANSISTOR, Type 2N1373	7210039-005
Q305	TRANSISTOR, Type 2N585	7210035-004
R101	RESISTOR, FIXED, COMPOSITION, 22K, 2W, 5%	0310032-223
R102	RESISTOR, FIXED, COMPOSITION, 4.7K, 1W, 5%	0310031-472
R104	RESISTOR, FIXED, COMPOSITION, 15K, 1W, 5%	0310031-153
R105	RESISTOR, FIXED, COMPOSITION, 47Ω, 2W, 5%	0310032-470
R106	RESISTOR, FIXED, COMPOSITION, 10K, 2W, 5%	0310032-103
R107	RESISTOR, FIXED, COMPOSITION, 39K, 1W, 5%	0310031-393
R108	RESISTOR, FIXED, COMPOSITION, 470Ω, 1W, 5%	0310031-471

Table 4-1. List of Replacement Parts (Contd)

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
R109	RESISTOR, FIXED, COMPOSITION, 470Ω, 1W, 5%	0310031-471
R110	RESISTOR, FIXED, WIRE-WOUND, 500Ω, 5W, 10%	5110010-028
R111	RESISTOR, FIXED, COMPOSITION, 330K, 2W, 5%	0310032-334
R112	RESISTOR, FIXED, COMPOSITION, 330K, 2W, 5%	0310032-334
R113	RESISTOR, FIXED, WIRE-WOUND, 4Ω, 5W, 10%	5110010-005
R114	RESISTOR, FIXED, WIRE-WOUND, 10K, 10W, 10%	5110016-103
R115	RESISTOR, FIXED, COMPOSITION, 470Ω, 1W, 5%	0310031-471
R201	RESISTOR, FIXED, COMPOSITION, 1K, 1/2W, 5%	0310030-102
R202	RESISTOR, FIXED, COMPOSITION, 1M, 1/2W, 5%	0310030-105
R204	RESISTOR, FIXED, COMPOSITION, 220K, 1/2W, 5%	0310030-224
R205	RESISTOR, FIXED, COMPOSITION, 5.6K, 1/2W, 5%	0310030-562
R206	RESISTOR, FIXED, COMPOSITION, 4.7M, 1/2W, 5%	0310030-475
R207	RESISTOR, FIXED, COMPOSITION, 680K, 1/2W, 5%	0310030-684

Table 4-1. List of Replacement Parts (Contd)

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
R208	RESISTOR, FIXED, COMPOSITION, 1M, 1/2W, 5%	0310030-105
R209	RESISTOR, FIXED, COMPOSITION, 1.5M, 1/2W, 5%	0310030-155
R210	RESISTOR, FIXED, COMPOSITION, 1K, 1/2W, 5%	0310030-102
R211	RESISTOR, FIXED, COMPOSITION, 47K, 1/2W, 5%	0310030-473
R212	RESISTOR, FIXED, COMPOSITION, 120K, 1W, 5%	0310031-124
R213	RESISTOR, FIXED, COMPOSITION, 82K, 1W, 5%	0310031-823
R214	RESISTOR, FIXED, COMPOSITION, 1K, 1/2W, 5%	0310030-102
R215	RESISTOR, FIXED, COMPOSITION, 220K, 1/2W, 5%	0310030-224
R216	RESISTOR, FIXED, COMPOSITION, 10M, 1/2W, 5%	0310030-106
R217	RESISTOR, FIXED, COMPOSITION, 3.3K, 1/2W, 5%	0310030-332
R218	RESISTOR, FIXED, COMPOSITION, 1K, 1/2W, 5%	0310030-102
R219	RESISTOR, FIXED, COMPOSITION, 1K, 1/2W, 5%	0310030-102
R220	RESISTOR, FIXED, COMPOSITION, 3.3K, 1/2W, 5%	0310030-332

Table 4-1. List of Replacement Parts (Contd)

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
R221	RESISTOR, FIXED, COMPOSITION, 3.3M, 1/2W, 5%	0310030-335
R222	RESISTOR, FIXED, COMPOSITION, 470K, 1/2W, 5%	0310030-474
R223	RESISTOR, FIXED, COMPOSITION, 220K, 1/2W, 5%	0310030-224
R224	RESISTOR, FIXED, COMPOSITION, 470K, 1/2W, 5%	0310030-474
R225	RESISTOR, FIXED, COMPOSITION, 150K, 1/2W, 5%	0310030-154
R226	RESISTOR, FIXED, COMPOSITION, 820Ω, 1/2W, 5%	0310030-821
R227	RESISTOR, FIXED, COMPOSITION, 3.3M, 1/2W, 5%	0310030-335
R228	RESISTOR, FIXED, COMPOSITION, 2.7M, 1/2W, 5%	0310030-275
R229	RESISTOR, FIXED, COMPOSITION, 220K, 1/2W, 5%	0310030-224
R230	RESISTOR, FIXED, COMPOSITION, 820K, 1/2W, 5%	0310030-824
R231	RESISTOR, FIXED, COMPOSITION, 10M, 1/2W, 5%	0310030-106
R301	RESISTOR, FIXED, COMPOSITION, 10M, 1/2W, 5%	0310030-106
R302	RESISTOR, FIXED, COMPOSITION, 1M, 1/2W, 5%	0310030-105

Table 4-1. List of Replacement Parts (Contd)

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
R303	RESISTOR, FIXED, COMPOSITION, 47K, 1/2W, 5%	0310030-473
R304	RESISTOR, FIXED, COMPOSITION, 6.8M, 1/2W, 5%	0310030-685
R305	RESISTOR, FIXED, COMPOSITION, 1M, 1/2W, 5%	0310030-105
R306	RESISTOR, FIXED, COMPOSITION, 1M, 1/2W, 5%	0310030-105
R307	RESISTOR, FIXED, COMPOSITION, 5.6K, 1/2W, 5%	0310030-562
R308	RESISTOR, FIXED, COMPOSITION, 68K, 1W, 5%	0310031-683
R309	RESISTOR, FIXED, COMPOSITION, 3.3K, 1/2W, 5%	0310030-332
R310	RESISTOR, FIXED, COMPOSITION, 120K, 2W, 5%	0310032-124
R311	RESISTOR, FIXED, COMPOSITION, 82K, 2W, 5%	0310032-823
R312	RESISTOR, FIXED, COMPOSITION, 47K, 2W, 5%	0310032-473
R314	RESISTOR, FIXED, COMPOSITION, 100Ω, 1/2W, 5%	0310030-101
R315	RESISTOR, FIXED, COMPOSITION, 68K, 1/2W, 5%	0310030-683

Table 4-1. List of Replacement Parts (Contd)

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
R316	RESISTOR, VARIABLE, COMPOSITION, 5K, 1/4W, 20%, linear	5010179-007
R317	RESISTOR, FIXED, COMPOSITION, 8.2K, 1/2W, 5%	0310030-822
R318	RESISTOR, FIXED, COMPOSITION, 47K, 1/2W, 5%	0310030-473
R319	RESISTOR, FIXED, COMPOSITION, 3.9K, 1/2W, 5%	0310030-392
R320	RESISTOR, FIXED, COMPOSITION, 18K, 1/2W, 5%	0310030-183
R321	RESISTOR, FIXED, COMPOSITION, 15K, 1/2W, 5%	0310030-153
R322	RESISTOR, FIXED, COMPOSITION, 22K, 1/2W, 5%	0310030-223
R323	RESISTOR, FIXED, COMPOSITION, 6.8K, 1/2W, 5%	0310030-682
R324	RESISTOR, FIXED, WIRE-WOUND, 10K, 20W, 5%	5102100
R325	RESISTOR, FIXED, COMPOSITION, 220Ω, 1/2W, 5%	0310030-221
R326	RESISTOR, FIXED, COMPOSITION, 15K, 1/2W, 5%	0310030-153
R327	RESISTOR, FIXED, COMPOSITION, 2.2K, 1/2W, 5%	0310030-222
R328	RESISTOR, FIXED, COMPOSITION, 1M, 1/2W, 5%	0310030-105

Table 4-1. List of Replacement Parts (Contd)

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
R329	RESISTOR, FIXED, COMPOSITION, 82Ω, 1/2W, 5%	0310030-820
R330	RESISTOR, FIXED, COMPOSITION, 1K, 1/2W, 5%	0310030-102
R331	RESISTOR, FIXED, COMPOSITION, 2.2K, 1/2W, 5%	0310030-222
R332	RESISTOR, FIXED, COMPOSITION, 39K, 1/2W, 5%	0310030-393
R333	RESISTOR, FIXED, COMPOSITION, 2.2K, 1/2W, 5%	0310030-222
R334	RESISTOR, FIXED, COMPOSITION, 39K, 1/2W, 5%	0310030-393
R335	RESISTOR, FIXED, COMPOSITION, 10K, 1/2W, 5%	0310030-103
R336	RESISTOR, FIXED, COMPOSITION, 10K, 1/2W, 5%	0310030-103
R337	RESISTOR, FIXED, COMPOSITION, 10K, 1/2W, 5%	0310030-103
R338	RESISTOR, FIXED, COMPOSITION, 1K, 1/2W, 5%	0310030-102
R339	RESISTOR, FIXED, COMPOSITION, 270Ω, 1/2W, 5%	0310030-271
R340	RESISTOR, FIXED, COMPOSITION, 1M, 1/2W, 5%	0310030-105
R341	RESISTOR, FIXED, COMPOSITION, 1M, 1/2W, 5%	0310030-105

Table 4-1. List of Replacement Parts (Contd)

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
R342	RESISTOR, FIXED, COMPOSITION, 39K, 2W, 5%	0310032-393
R343	RESISTOR, FIXED, COMPOSITION, 560Ω, 1/2W, 5%	0310030-561
R344	RESISTOR. FIXED, COMPOSITION, 2.2M, 1/2W, 5%	0310030-225
R345	RESISTOR, FIXED, COMPOSITION, 180K, 2W, 5%	0310032-184
R346	RESISTOR, FIXED, COMPOSITION, 220K, 1W, 5%	0310031-224
R347	RESISTOR, FIXED, COMPOSITION, 56K, 1W, 5%	0310031-563
R348	RESISTOR, FIXED, COMPOSITION, 10M, 1/2W, 5%	0310030-106
R349	RESISTOR, FIXED, COMPOSITION, 39K, 2W, 5%	0310032-393
R350	RESISTOR, FIXED, COMPOSITION, 180K, 1W, 5%	0310031-184
R351	RESISTOR, FIXED, COMPOSITION, 47K, 1/2W, 5%	0310030-473
R352	RESISTOR, VARIABLE, COMPOSITION, 10K, 1/4W, 20%, linear	5010179-008
R353	RESISTOR, FIXED, COMPOSITION, 470K, 1/2W, 5%	0310030-474
R354	RESISTOR, FIXED, COMPOSITION, 6.8M, 1/2W, 5%	0310030-685

Table 4-1. List of Replacement Parts (Contd)

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
R355	RESISTOR, FIXED, COMPOSITION, 47K, 1/2W, 5%	0310030-473
R356	RESISTOR, FIXED, COMPOSITION, 33K, 1/2W, 5%	0310030-333
R357	RESISTOR, FIXED, COMPOSITION, 33K, 1/2W, 5%	0310030-333
R401	RESISTOR, VARIABLE, WIRE-WOUND, 10Ω, 1.28%	5010200-002
R402	RESISTOR, VARIABLE, WIRE-WOUND, 100Ω, 0.68%	5010200-004
R403	RESISTOR, VARIABLE, WIRE-WOUND, 1K, 0.34%	5010200-012
R405	RESISTOR, VARIABLE, WIRE-WOUND, 10Ω, 1.28%	5010200-002
R406	RESISTOR, FIXED, WIRE-WOUND, 1Ω, 0.1%	5210100-011
R407	RESISTOR, FIXED, WIRE-WOUND, 2Ω, 0.1%	5210100-012
R408	RESISTOR, FIXED, WIRE-WOUND, 4Ω, 0.1%	5210100-013
R409	RESISTOR, FIXED, WIRE-WOUND, 4Ω, 0.1%	5210100-013
R410	RESISTOR, FIXED, WIRE-WOUND, 10Ω, 0.01%	5210100-008
R411	RESISTOR, FIXED, WIRE-WOUND, 20Ω, 0.01%	5210100-009

Table 4-1. List of Replacement Parts (Contd)

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
R412	RESISTOR, FIXED, WIRE-WOUND, 40Ω, 0.01%	5210100-010
R413	RESISTOR, FIXED, WIRE-WOUND, 40Ω, 0.01%	5210100-010
R414	RESISTOR, FIXED, WIRE-WOUND, 100Ω, 0.01%	5210100-005
R415	RESISTOR, FIXED, WIRE-WOUND, 200Ω, 0.01%	5210100-006
R416	RESISTOR, FIXED, WIRE-WOUND, 400Ω, 0.01%	5210100-007
R417	RESISTOR, FIXED, WIRE-WOUND, 400Ω, 0.01%	5210100-007
R418	RESISTOR, FIXED, WIRE-WOUND, 1K, 0.005%	5210100-002
R419	RESISTOR, FIXED, WIRE-WOUND, 2K, 0.005%	5210100-003
R420	RESISTOR, FIXED, WIRE-WOUND, 4K, 0.005%	5210100-004
R421	RESISTOR, FIXED, WIRE-WOUND, 4K, 0.005%	5210100-004
R422	RESISTOR, FIXED, WIRE-WOUND, 9.995K, 0.03%	5210093-001
R423	RESISTOR, VARIABLE, WIRE-WOUND, 10Ω, 1.28%	5010200-101
R424	RESISTOR, FIXED, WIRE-WOUND, 19.99K, 0.03%	5210093-002

Table 4-1. List of Replacement Parts (Contd)

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
R425	RESISTOR, VARIABLE, WIRE-WOUND, 20Ω, 1.27%	5010200-102
R426	RESISTOR, VARIABLE, WIRE-WOUND, 50Ω, 0.89%	5010200-103
R427	RESISTOR, FIXED, WIRE-WOUND, 39.98K 0.03%	5210093-003
R428	RESISTOR, FIXED, WIRE-WOUND, 39.98K, 0.03%	5210093-003
R429	RESISTOR, VARIABLE, WIRE-WOUND, 50Ω, 0.89%	5010200-103
R430	RESISTOR, VARIABLE, WIRE-WOUND, 100Ω, 0.68%	5010200-104
R431	RESISTOR, FIXED, WIRE-WOUND, 99.95K 0.03%	5210093-004
R432	RESISTOR, FIXED, WIRE-WOUND, 199.9K, 0.03%	5210093-005
R434	RESISTOR, FIXED, WIRE-WOUND, 399.8K, 0.03%	5210093-006
R438	RESISTOR, FIXED, WIRE-WOUND, 399.8K, 0.03%	5210093-006
R442	RESISTOR, VARIABLE, WIRE-WOUND, 500Ω, 0.44%	5010200-106
R443	RESISTOR, VARIABLE, WIRE-WOUND, 500Ω, 0.44%	5010200-106
R444	RESISTOR, VARIABLE, WIRE-WOUND, 200Ω, 0.56%	5010200-105
R446	RESISTOR, FIXED, WIRE-WOUND, 5.895K, 0.03%	5210076-013

Table 4-1. List of Replacement Parts (Contd)

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
R447	RESISTOR, FIXED, WIRE-WOUND, 58.95K, 0.03%	5210076-014
R448	RESISTOR, FIXED, WIRE-WOUND, 589.5K, 0.03%	5210076-015
R449	RESISTANCE WIRE, 0.4Ω	7610036-002
R450	RESISTANCE WIRE, 0.4Ω	7610036-002
R451	RESISTANCE WIRE, 0.2Ω	7610036-002
R452	RESISTANCE WIRE, 0.1Ω	7610036-002
R501	RESISTOR, FIXED, COMPOSITION, 560K, 2W, 5%	0310032-564
R502	RESISTOR, FIXED, COMPOSITION, 560K, 2W, 5%	0310032-564
R503	RESISTOR, FIXED, COMPOSITION, 560K, 2W, 5%	0310032-564
R504	RESISTOR, FIXED, COMPOSITION, 560K, 2W, 5%	0310032-564
R801	RESISTOR, FIXED, COMPOSITION, 270K, 1/2W, 5%	0310030-274
R802	RESISTOR, FIXED, COMPOSITION, 220Ω, 1/2W, 5%	0310030-221
R803	RESISTOR, FIXED, COMPOSITION, 560K, 1/2W, 5%	0310030-564
R806	RESISTOR, FIXED, COMPOSITION, 10M, 1/2W, 5%	0310030-106
R807	RESISTOR, FIXED, COMPOSITION, 22K, 1/2W, 5%	0310030-223

Table 4-1. List of Replacement Parts (Contd)

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
R808	RESISTOR, VARIABLE, COMPOSITION, 10K, 1/2W, 10%	5010181-003
R809	RESISTOR, FIXED, COMPOSITION, 100Ω, 1/2W, 5%	0310030-101
R810	RESISTOR, FIXED, COMPOSITION, 560K, 1/2W, 5%	0310030-564
R811	RESISTOR, VARIABLE, COMPOSITION, 10K, 1/2W, 10%	5010181-003
R812	RESISTOR, FIXED, COMPOSITION, 47Ω, 1/2W, 5%	0310030-470
R813	RESISTOR, FIXED, COMPOSITION, 270K, 1/2W, 5%	0310030-274
R814	RESISTOR, VARIABLE, COMPOSITION, 10K, 1/2W, 10%	5010181-003
R901	RESISTOR, FIXED, COMPOSITION, 1M, 1/2W, 5%	0310030-105
R902	RESISTOR, FIXED, COMPOSITION, 1M, 1/2W, 5%	0310030-105
R903	RESISTOR, FIXED, COMPOSITION, 1M, 1/2W, 5%	0310030-105
R904	RESISTOR, FIXED, COMPOSITION, 1M, 1/2W, 5%	0310030-105
R906	RESISTOR, FIXED, COMPOSITION, 10Ω, 1/2W, 5%	0310030-100
R910	RESISTOR, FIXED, COMPOSITION, 270Ω, 1W, 5%	0310031-271
R911	RESISTOR, FIXED, COMPOSITION, 27Ω, 1W, 5%	0310031-270

Table 4-1. List of Replacement Parts (Contd)

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
R912	RESISTOR, FIXED, COMPOSITION, 100Ω, 1W, 5%	0310031-101
R913	RESISTOR, FIXED, COMPOSITION, 82Ω, 1W, 5%	0310031-820
R914	RESISTOR, FIXED, COMPOSITION, 220K, 2W, 5%	0310032-224
R915	RESISTOR, FIXED, COMPOSITION, 270K, 2W, 5%	0310032-274
R916	RESISTOR, FIXED, COMPOSITION, 100Ω, 2W, 5%	0310032-101
R917	RESISTOR, FIXED, COMPOSITION, 10Ω, 1/2W, 5%	0310030-100
R918	RESISTOR, FIXED, COMPOSITION, 10K, 1/2W, 5%	0310030-103
R919	RESISTOR, FIXED, COMPOSITION, 120Ω, 1W, 5%	0310031-121
S401	SWITCH, ROTARY, 1P11T, 3-Deck	6210060-001
S402	SWITCH, ROTARY, 1P11T, 3-Deck	6210060-001
S403	SWITCH, ROTARY, 1P11T, 3-Deck	6210060-001
S404	SWITCH, ROTARY, 1P11T, 3-Deck	6210060-001
S405	SWITCH, ROTARY, 1P11T, 3-Deck	6210060-001
S406	SWITCH, ROTARY, 1P11T, 3-Deck	6210060-001
S407	SWITCH, ROTARY, 1P11T, 4-Deck	6210074-001
S901	SWITCH, ROTARY, SPST, Modified	6210018-005
S902	SWITCH, ROTARY, SPST, Modified	6210018-006

Table 4-1. List of Replacement Parts (Contd)

CIRCUIT REF.	DESCRIPTION	KIN TEL PART NO.
S903	SWITCH, ROTARY, 1P4T, 1-Deck	6210062-001
S904	SWITCH, ROTARY, 3P3T, 2-Deck	6210063-001
S905	SWITCH, ROTARY, 3P3T, 1-Deck	6210061-001
T901	TRANSFORMER, POWER, Special	6510122-001
V201	TUBE, ELECTRONIC, Type 5751	7302812
V202	TUBE, ELECTRONIC, Type 6AU6A	7010041-001
V203	TUBE, ELECTRONIC, Type 6AU6A	7010041-001
V204	TUBE, ELECTRONIC, Type 6AU6A	7010041-001
V301	TUBE, ELECTRONIC, Type 6CB6A	7002773
V302	TUBE, ELECTRONIC, Type 6CB6A	7002773
V303	TUBE, ELECTRONIC, Type 6AU8A	7007118
V901	TUBE, ELECTRONIC, Type 8068	7010045-001
*V901	TUBE, ELECTRONIC, Type 6889	7010040-001

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*Some instruments are equipped with tube type 6889.

NO LONGER APPLICABLE

Table 4-2. Recommended Spare Part Kits for KIN TEL Model 303A DC Voltage Standard

KIN TEL PART NO.	DESCRIPTION	KIT NUMBER		
		7813A-PK001	7813A-PK005	7813A-PK025
		STOCK LEVEL		
		1 unit	5 units	25 units
0510059	Capacitor, electrolytic, 20/20 µf, 150V	1	2	5
0510089-020	Capacitor, electrolytic, 1000 µf, 6V	3	9	15
0510092-020	Capacitor, electrolytic, 1000 µf, 15V	2	6	10
0510121-006	Capacitor, electrolytic, 40/20 µf, 450V	1	2	5
0510122-002	Capacitor, electrolytic, 20 µf, 450V	2	5	15
0810013-001	Capacitor, plastic, 8 µf, 2KV	1	2	5
3510004	Semiconductor, diode, type 1N628	2	4	10
3510022-004	Semiconductor, diode, type RS-6	1	2	5
3510042-012	Semiconductor, diode, type 1N714	1	2	5
3510053-001	Semiconductor, diode, type CER71A	16	40	100
3510053-005	Semiconductor, diode, type HC71	2	4	10
3710006-008	Relay, armature, 3 form C closures, 28VDC, 500Ω	1	1	2
3710034-001	Relay, armature, 2 form C closures, 10KΩ	1	1	2
6210018-006	Switch, rotary, SPST, modified	1	1	2
6210062-001	Switch, rotary, SP4T, 1-deck	1	1	2
6210063-001	Switch, rotary, 3P3T, 2-deck	1	1	2
6310018-001	Chopper, SPDT, 6.3V, 60 cps, 86Ω	1	2	5
7010041-001	Tube, electron, type 6AU6A	2	5	10

Table 4-2. Recommended Spare Part Kits for KIN TEL Model 303A DC Voltage Standard (Contd)

KIN TEL PART NO.	DESCRIPTION	STOCK LEVEL		
		1 unit	5 units	25 units
7002773	Tube, electron, type 6CB6A	1	2	5
7007118	Tube, electron, type 6AU8A	1	2	5
*7010040-001	Tube, electron, type 6889	1	2	5
7010045-001	Tube, electron, type 8068	1	2	5
7210035-004	Transistor, type 2N585	1	2	5
7210039-005	Transistor, type 2N1373	4	8	20
7302812	Tube, electron, type 5751	1	2	5
7813091-001	Assembly, Reference Unit	1	1	2
7816411-001	Assembly, Range and Decade Resistors	0	0	1
7813065-001	Assembly, Power Tube and Relay	0	0	1
7813101-001	Assembly, Power Supply	0	0	1
7813201-001	Assembly, Carrier and Wideband Amplifiers	0	0	1
7813301-001	Assembly, DC Output Amplifier	0	0	1
7813501-001	Assembly, High Voltage Power Supply	0	0	1

*For instruments equipped with tube type 6889 the spare part kit numbers are 7813A-PK001A, 7813A-PK005A, and 7813A-PK025A.

NO LONGER APPLICABLE

WARRANTY

COHU ELECTRONICS, INC., Kin Tel Division, warrants equipment manufactured to be free from defects of material and workmanship. Any part or parts will be repaired or replaced when proven by COHU examination to have been defective within one year (90 days for batteries, fuses, transistors and tubes) from date of shipment to the original purchaser. All warranty repairs will be performed at the factory or as otherwise authorized by COHU in writing. Transportation charges shall be prepaid by purchaser.

This warranty does not extend to COHU equipment subjected to misuse, accident, neglect or improper application; nor repaired or altered by other than COHU or those authorized by COHU in writing.

This warranty is in lieu of all other warranties express or implied. COHU shall not be liable for collateral or consequential damages.

For customer convenience, service departments are maintained throughout the United States by COHU Field Engineering Representatives.

COHU
ELECTRONICS, INC
KIN TEL DIVISION

Electro Scientific Industries
7524 S. W. MACADAM AVE. • PORTLAND 19, OREGON

STANDARDS

APRIL 1963

MODEL

SR 1010

Instruction Manual

DECADE RESISTANCE STANDARD

T. O. 33-A1-12-462-1

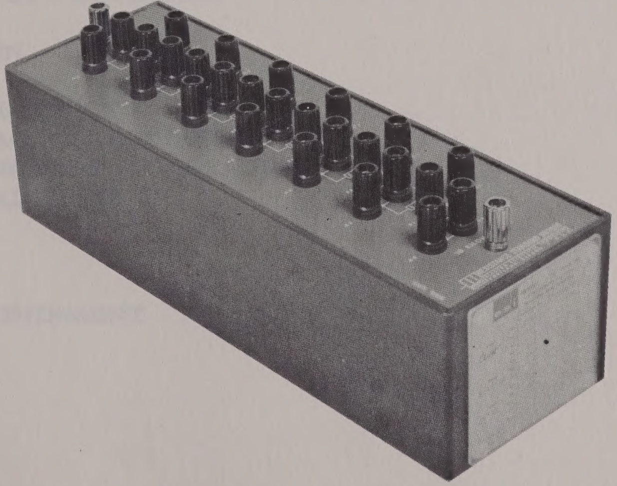

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TABLE OF CONTENTS

I DESCRIPTION AND SPECIFICATIONS

- 1.1 DESCRIPTION
- 1.2 SPECIFICATIONS

II OPERATING INSTRUCTIONS

- 2.1 BASIC OPERATIONS
- 2.2 CONNECTIONS
- 2.3 HIGH ACCURACY CALIBRATION TRANSFER

III THEORY

- 3.1 JUNCTION RESISTANCE EFFECTS
- 3.2 INSULATION RESISTANCE EFFECTS
- 3.3 BASIC TRANSFER ACCURACY
- 3.4 FOUR-TERMINAL PARALLELING
- 3.5 LINEARITY DEVIATION

IV CALIBRATION

- 4.1 INTRODUCTION
- 4.2 EQUIPMENT REQUIRED
- 4.3 SEQUENCE OF CALIBRATION
- 4.4 SPECIAL TESTS

V PARTS LIST

DAMAGE IN SHIPMENT
WARRANTY

SECTION I

DESCRIPTION AND SPECIFICATIONS

1.1 DESCRIPTION

Each MODEL SR 1010 RESISTANCE TRANSFER STANDARD is a resistance box containing twelve nominally equal precision resistors. SR 1010 boxes are available in various resistance values.

There are three basic ways of using a Model SR 1010, depending upon the accuracy required. In many applications, the resistor adjustment accuracy is high enough that the resistors can be assumed to have exactly their nominal values. For higher accuracy, certified calibration data can be used to correct the resistance values. For the ultimate accuracy in a laboratory having a high-accuracy one ohm reference standard, a set of SR 1010 boxes can be used to transfer calibration from the one ohm reference to the entire chain of resistance measuring equipment and standards in the laboratory with an accuracy at the time of calibration much better than the long-term accuracy to which any of the equipment could be certified.

Each MODEL SR 1010 RESISTANCE TRANSFER STANDARD has a calibration chart attached to it, giving the measured deviation of each resistor from its nominal value. The chart also includes the calculated average deviations of resistor groups for use in series, parallel and series-parallel groups. The ESI calibration data supplied is directly traceable to standards certified by the National Bureau of Standards. Blank calibration charts are available for subsequent calibrations. The excellent stability and unusually low temperature coefficient of the resistors used in the SR 1010 assure the maintenance of high accuracy between calibration periods and over normal temperature ranges.

The design of the MODEL SR 1010 RESISTANCE TRANSFER STANDARD and its accessories facilitates the transfer of resistance calibration from one resistance level to another. The series, parallel and series-parallel connections of resistor groups in an SR 1010 to give resistance values of 0.1, 1 and 10 times the individual resistor value is particularly useful in calibrating a set of SR 1010's to a short-term accuracy much better than any long-term certification. A laboratory having one or more Thomas-pattern one ohm resistors as its reference standard can use a set of SR 1010 boxes to calibrate measurements over a wide resistance range to very nearly the same accuracy as that of its one ohm reference standard.

The resistors in an SR 1010 are permanently connected in series. The provision of two binding post terminals at each junction allows accurate four-terminal measurement of any resistor or series group of resistors. Accessories are available for parallel and series-parallel connections. A pair of shorting bars, ESI Model SB 103, is used to connect any number of resistors in parallel or a group of nine resistors in series-parallel. Two different compensation networks, ESI Models PC 101 and SPC 102, are used to eliminate loss of accuracy at the lower resistance levels in making four-terminal measurements of ten resistors in parallel and nine resistors in series-parallel. As a result of the special design of the four-terminal junctions between binding posts and resistors, and the use of the parallel and series-parallel compensation networks, the actual values of four-terminal series, parallel and series-parallel resistor groups will agree with their values calculated from individual resistor values to better than ±0.1 microhm.

The SR 1010 owes its high accuracy and stability to the precision resistors used. The resistors are unifilar-wound on specially processed mica cards, and use a modern alloy resistance wire which has excellent stability, extremely low temperature coefficient and negligible thermal emf to copper. All the resistors in an SR 1010 are wound from the same spool of wire in order to yield the best temperature coefficient and stability matching between resistors. Each resistor is carefully built and inspected to insure maximum control of quality. Resistors for use in Model SR 1010's are selected for minimum temperature coefficient and given a rigorous accelerated aging treatment. The complete resistance transfer standard is given additional stabilization treatment, followed by an extended series of tests to ensure that every SR 1010 conforms to the highest standards of quality.

1.2 SPECIFICATIONS

MODEL SR 1010

CALIBRATION ACCURACY: ±0.002%. Resistance value supplied determined by a four-terminal measurement, at an ambient temperature of 23°C with negligible power dissipation, with calibration traceable to the National Bureau of Standards.

ADJUSTMENT ACCURACY: Each resistor adjusted to ±0.005% of nominal value.

LONG-TERM STABILITY: ±0.005%, guaranteed for one year.

SHORT-TERM STABILITY: During comparison or substitution measurements, the resistance of each resistor will remain constant within ±0.0001% (one part per million) at constant temperature and sufficiently low power to avoid internal heating (see power coefficient ratings).

TERMINAL RESISTANCE: Two-terminal resistance values are approximately 0.3 milliohms higher than the calibrated four-terminal values (0.15 milliohm per terminal). If a "zero-resistance" reading measured between the pair of terminals at any junction is subtracted from the two-terminal measured value, the resulting value will agree with the four-terminal calibration within 0.05 milliohm, or within the reproducibility of the two-terminal connection resistance to the terminals, whichever is the greater.

JUNCTION TRANSRESISTANCE: Each junction guaranteed to have transresistance between any lead pairs less than 1/2 microhm or 0.1ppm of resistance per step, whichever is larger.

MAXIMUM POWER RATINGS: One watt continuous in one resistor alone or five watts distributed over nine or more resistors.

POWER COEFFICIENT: 1 ohm to 10 ohms:
±0.03%/watt in one resistor alone.
±0.006%/watt distributed over nine or more resistors.

100 ohms to 100 kilohms:
±0.01%/watt in one resistor alone.
±0.002%/watt distributed over nine or more resistors.

STANDARD SR 1010 VALUES:
PER STEP

(R) VALUE - PER STEP		1Ω	10Ω	100Ω	1K	10K	100K
ONE RESISTOR ALONE	MAXIMUM MILLIAMPERES	1000	320	100	32	10	3.2
	MAXIMUM VOLTS	1	3.2	10	32	100	320
9 RESISTORS IN SERIES-PARALLEL (R)	MAXIMUM MILLIAMPERES	2300	710	230	71	23	7.1
	MAXIMUM VOLTS	2.3	7.1	23	71	230	710
10 RESISTORS IN PARALLEL (R/10)	MAXIMUM MILLIAMPERES	7100	2300	710	230	71	23
	MAXIMUM VOLTS	0.71	2.3	7.1	23	71	230
10 RESISTORS IN SERIES (10R)	MAXIMUM MILLAIMPERES	710	230	71	23	7.1	2.3
	MAXIMUM VOLTS	7.1	23	71	230	710	2300*

* Do not exceed 1500 peak volts to case.

TEMPERATURE COEFFICIENT: 1 ohm to 10 ohms ±0.0015%/°C
100 ohms to 100 kilohms ±0.0005%/°C

BREAKDOWN VOLTAGE: 1500 volts to case

WEIGHT: 3-1/4 lbs net

MODEL SB 103 SHORTING BARS

FUNCTION: A pair of shorting bars used to connect any number of resistors of a MODEL SR 1010 RESISTANCE TRANSFER STANDARD in parallel or nine of its resistors in a series-parallel arrangement.

EFFECTIVE RESISTANCE AND ACCURACY: See COMBINED FUNCTIONAL SPECIFICATIONS.

RESISTANCE: End to end: approximately 100μ ohms/bar.

MAXIMUM CURRENT: 10 amps/bar

MODEL PC 101 PARALLEL COMPENSATION NETWORK

FUNCTION: Used in addition to an SB 103 pair for the four-terminal parallel connection of ten resistors in an SR 1010 to yield the same resistance as the value calculated from individual four-terminal resistor measurements.

EFFECTIVE RESISTANCE AND ACCURACY:	See COMBINED FUNCTIONAL SPECIFICATIONS.
RESISTOR MATCHING:	Matched to ±0.05%
MAXIMUM CURRENT:	2.5 amps
BREAKDOWN VOLTAGE:	1500 volts to case

MODEL SPC 102 SERIES-PARALLEL COMPENSATION NETWORK

FUNCTION: Used in addition to an SB 103 pair for the four-terminal series-parallel connection of nine resistors in an SR 1010, to yield the same resistance as the value calculated from individual four-terminal resistor measurements.

EFFECTIVE RESISTANCE AND ACCURACY:	See COMBINED FUNCTIONAL SPECIFICATIONS.
RESISTOR MATCHING:	Matched to ±0.05%
MAXIMUM CURRENT:	2.0 amps
BREAKDOWN VOLTAGE:	1500 volts to case

COMBINED FUNCTIONAL SPECIFICATIONS:

Resistor grouping	Ten resistors in parallel	Nine resistors in series-parallel	Ten resistors in series
Nominal value (relative to individual resistor value R)	0.1R	R	10R
Four-terminal measurement	Resistance added to value calculated from individual resistor values (value and tolerance in microhms)		
With SB 103 and PC 101 or SPC 102	0±0.1	0±1	
With SB 103 alone	50±10	200±40	
With no accessories			0±10
Two-terminal measurement			
With SB 103	150±30	300±60	
With no accessories			300±60

SECTION II

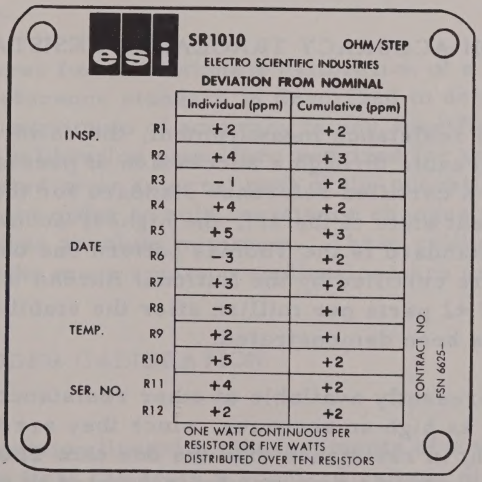
OPERATING INSTRUCTIONS

2.1 BASIC OPERATIONS

2.1.1 USING THE CALIBRATION CHART

The calibration chart on the end of each SR 1010 gives resistance calibration data for individual resistors and groups of resistors in the SR 1010, in terms of their deviation from nominal value, expressed in parts per million. These values are based on four-terminal measurements; two-terminal measurements must be corrected for the connection resistances listed in the specifications and discussed in Section 2.2 (Connections).

A sample calibration chart is shown in Figure 2.1.1.



SR1010 OHM/STEP

ELECTRO SCIENTIFIC INDUSTRIES

DEVIATION FROM NOMINAL

INSP.

DATE

TEMP.

SER. NO.

	Individual (ppm)	Cumulative (ppm)
R1	+2	+2
R2	+4	+3
R3	−1	+2
R4	+4	+2
R5	+5	+3
R6	−3	+2
R7	+3	+2
R8	−5	+1
R9	+2	+1
R10	+5	+2
R11	+4	+2
R12	+2	+2

ONE WATT CONTINUOUS PER RESISTOR OR FIVE WATTS DISTRIBUTED OVER TEN RESISTORS

CONTRACT NO.

FSN 6625–

FIG. 2.2.1

The first column gives the measured deviation of each resistor from its nominal value. The second column gives the cumulative average of the deviation figures in the first column, rounded to the same number of significant figures as the first column. For example, to the right of R7, the figure in the first column is the measured deviation of R7 from nominal, while the figure in the second column is the calculated average deviation of resistors R1 through R7.

The cumulative average deviation in the second column calibrates any series, parallel or series-parallel connection of the corresponding group of resistors in which the power divides equally among all the resistors in the group. For example, the first nine resistors in a one ohm per step box can be connected in series for a nominal value of nine ohms, in parallel for one-ninth of an ohm, or in series-parallel for one ohm; the actual value of each of these three alternate connections will be exactly the same number of parts per million away from the nominal value for that connection.

The calibration chart data supplied initially with each SR 1010 is traceable to the National Bureau of Standard with the specified accuracy under the stated laboratory environmental conditions. A set of SR 1010's can be easily recalibrated relative to any one ohm reference standard, using the procedures described in Section IV.

2.1.2 HIGH-ACCURACY TRACEABLE RESISTANCE MEASUREMENTS

In precision resistance measurement, the calibration of any resistor must be traceable through a succession of precise resistance comparisons to a certified reference standard for the unit of resistance. At the present state of the art, the highest-accuracy type of resistance reference standard is the Thomas pattern one ohm resistor. These resistors are certified by the National Bureau of Standards to an accuracy of ±2 parts per million after the stability of the particular resistor has been demonstrated.

Standards presently available at other resistance values cannot be certified to as high an accuracy, since they are typically somewhat less constant in resistance than the one ohm Thomas pattern over extended periods of time, or when subjected to environmental changes or mechanical shock. The short-term stability of a precision resistor in a laboratory environment, however, is typically much better than its long-term calibration accuracy. The accuracy of a calibration certificate must reflect this possible long-term instability, but a fresh calibration at the time of use may be far more accurate. Thus the laboratory equipped to trace all of its measurements to one ohm reference standards can calibrate its entire chain of resistance measuring equipment and resistance standards over a wide range of values to a short-term calibration accuracy much better than the accuracy to which such equipment could be certified for use over a long period of time or after transportation from one laboratory to another.

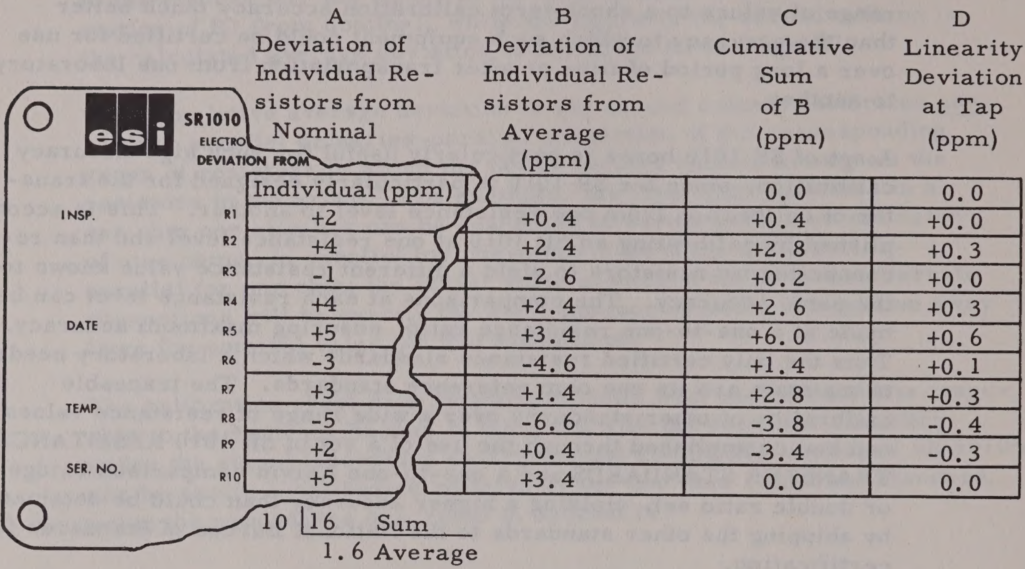
A set of SR 1010 boxes is particularly useful for such high-accuracy calibration, since the SR 1010 is particularly designed for the transfer of calibration from one resistance level to another. This is accomplished by calibrating an SR 1010 at one resistance level and then reconnecting its resistors to yield a different resistance value known to the same accuracy. The comparisons at each resistance level can be made at a one-to-one resistance ratio, ensuring maximum accuracy. Thus the only certified resistance standards which a laboratory needs to maintain are its one ohm reference standards. The traceable calibration of other standards over a wide range of resistance values can be accomplished through the use of a set of SR 1010 RESISTANCE TRANSFER STANDARDS and a one-to-one Kelvin comparison bridge or double ratio set, yielding a higher accuracy than could be obtained by shipping the other standards to the National Bureau of Standards for certification.

The procedures for the complete calibration of a set of SR 1010's from a one ohm reference standard is described in detail in Section IV. For the absolute maximum of accuracy in any specific calibration, those parts of the calibration procedure required for that application should be incorporated as an integral part of the operating procedure at the time of use, in order to hold resistance changes with time or ambient conditions to an absolute minimum. These calibration transfer procedures for the more common applications are described in Section 2.3.

2.1.3 DIVIDER CALIBRATION

To make precision linearity measurements of a voltage divider it is necessary to first calibrate a standard voltage divider. Due to its excellent short term stability and its four-terminal construction which makes it simple to calibrate, the ESI MODEL SR 1010 is ideal for use as such a standard voltage divider.

The following outlines the procedure for calibrating the SR 1010 as a voltage divider with ten equal steps, using the data given on its calibration chart. If the calibration chart has not been verified recently refer to Section 4.3.3 (Calibration of Individual Resistors).


esi
SR1010
ELECTRO
DEVIATION FROM
INSP.
DATE
TEMP.
SER. NO.

	A Deviation of Individual Resistors from Nominal	B Deviation of Individual Resistors from Average (ppm)	C Cumulative Sum of B (ppm)	D Linearity Deviation at Tap (ppm)
	Individual (ppm)		0.0	0.0
R1	+2	+0.4	+0.4	+0.0
R2	+4	+2.4	+2.8	+0.3
R3	-1	-2.6	+0.2	+0.0
R4	+4	+2.4	+2.6	+0.3
R5	+5	+3.4	+6.0	+0.6
R6	-3	-4.6	+1.4	+0.1
R7	+3	+1.4	+2.8	+0.3
R8	-5	-6.6	-3.8	-0.4
R9	+2	+0.4	-3.4	-0.3
R10	+5	+3.4	0.0	0.0
10	16 Sum			
	1.6 Average			

FIG. 2.1.3

1)	Add up the deviations from nominal of the first ten resistors of the SR 1010.	These are the values given in the first column of the calibration chart on the end of the SR 1010, see Figure 2.1.3 column A.
2)	Divide this sum by ten to find the average deviation.	
3)	Subtract the average deviation from each of the ten individual deviations.	See Figure 2.1.3 column B.

4) Starting with the first deviation from average, sum up all the deviations from average through each of the ten taps. For example the cumulative sum for the third tap would be the sum of the first, second and third deviations from average, for the example shown in Figure 2.1.3 this would be 0.4+2.4-2.6= 0.2.

See Figure 2.1.3 column C. The last figure in this column should always be zero.

5) Divide each of the cumulative sums by ten to get the linearity deviation at each tap.

See Figure 2.3.1 column D.

The calibrated SR 1010 can now be used as a standard voltage for calibrating other dividers. The following outlines the procedure for comparing the two.

6) Connect the SR 1010 and a microvoltmeter to the divider to be calibrated as shown in Section 2.2.4.

7) Adjust the end correcting potentiometers as described in Figure 2.2.4b.

8) Connect the microvoltmeter between corresponding taps on the SR 1010 and divider to be calibrated, and measure the deviation of the output of the unknown divider from the output of the SR 1010 at each tap.

The linearity deviation of the unknown divider will be

$$L^r_{unk} = \frac{V_{\mu v}}{E_{in}} + L^r_{std}$$

where:

L^r_{unk} is the linearity deviation of the unknown divider at the rth tap.

$V_{\mu v}$ is the reading of the microvoltmeter.

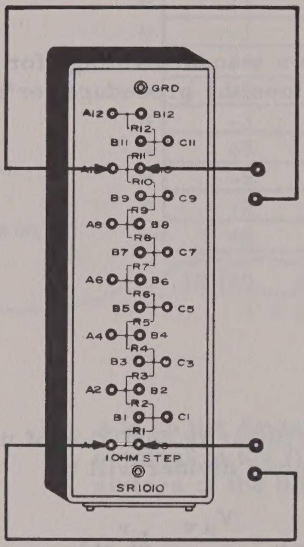
E_{in} is the voltage applied to the input of the dividers.

L^r_{std} is the linearity deviation of the SR 1010 for corresponding tap. (Column D)

2.2 CONNECTIONS

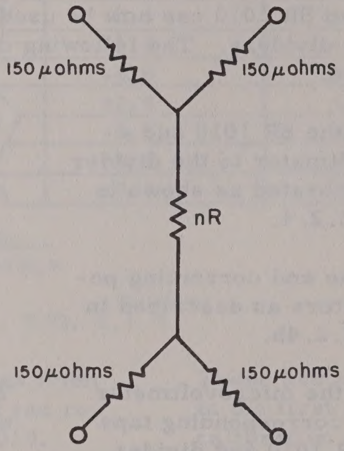
2.2.1 SINGLE RESISTOR OR SERIES GROUP

The SR 1010 was designed for use as a four-terminal resistor. The four connections are made to the two pairs of binding posts at either end of any of the resistors. The resistors are internally connected in series; to connect to n resistors in series it is only necessary to connect to the opposite ends of the 1st and nth resistors, see Figure 2.2.1a.



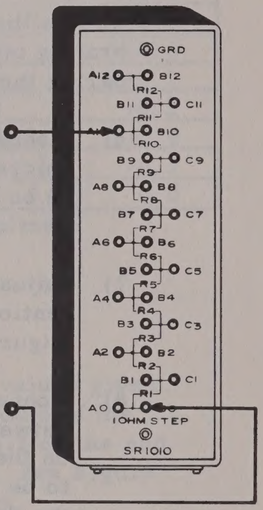
Four-terminal connection of ten resistors in series.

FIG. 2.2.1a



Equivalent circuit of n resistors in series.

FIG. 2.2.1b



Two-terminal connection of ten resistors in series.

FIG. 2.2.1c

The junction design that connects the resistors in series and to the binding post terminals is such that it contributes less than one microhm resistance to that of a four-terminal measurement of the individual resistors.

The SR 1010 may also be used as a two-terminal resistor; however, the calibrated four-terminal value must be corrected for the terminal resistance. Due to the design of the terminals at the end of each resistor it makes no difference which one is used for a two-terminal measurement. The resistance contributed by these terminals will be within ±0.06 milliohms of the resistance measured between the pair of terminals connected to the same end of any resistor, (about 0.3 milliohms), see Figure 2.2.1d.

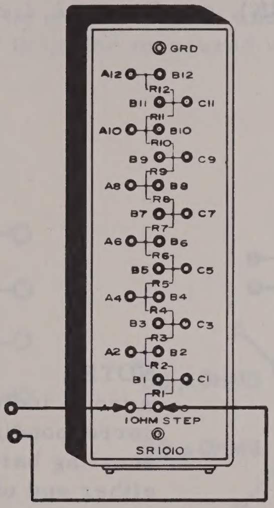
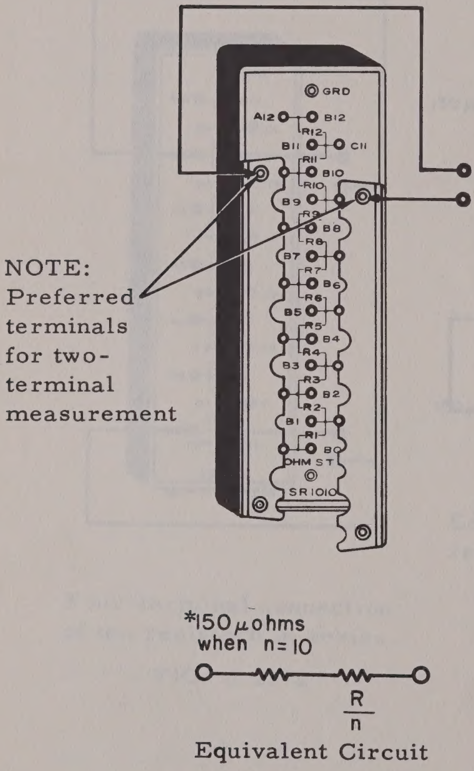


FIG. 2.2.1d

2.2.2 PARALLEL GROUP OF RESISTORS

Any number of resistors of a SR 1010 can be connected in parallel by means of shorting bars (ESI MODEL SB 103 or equivalent), see Figure 2.2.2a. For individual resistors of less than one hundred ohms, the paralleling leads and contact resistance may cause significant errors.

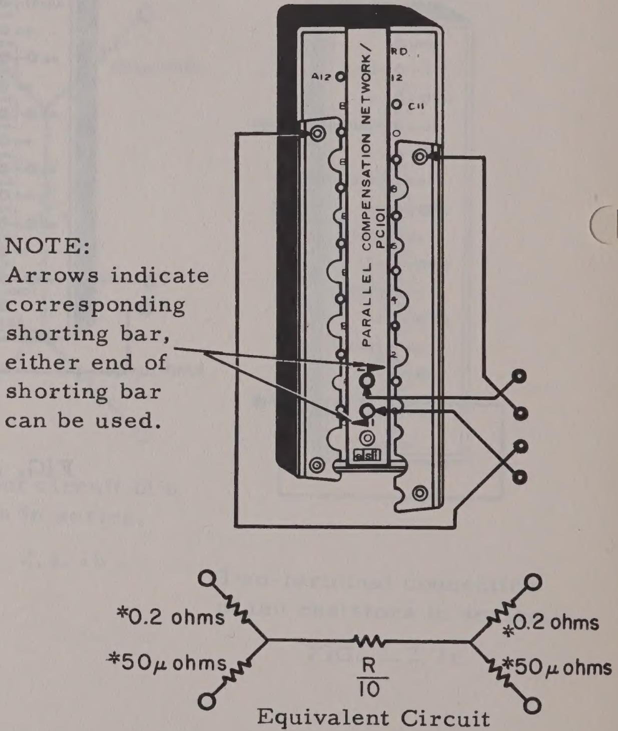
In connecting ten resistors in parallel, these errors can be essentially eliminated by use of a special compensation network for making four-terminal parallel connections (ESI MODEL PC 101 PARALLEL COMPENSATION NETWORK), see Figure 2.2.2b.



NOTE: Preferred terminals for two-terminal measurement

Equivalent Circuit

FIG. 2.2.2a



NOTE: Arrows indicate corresponding shorting bar, either end of shorting bar can be used.

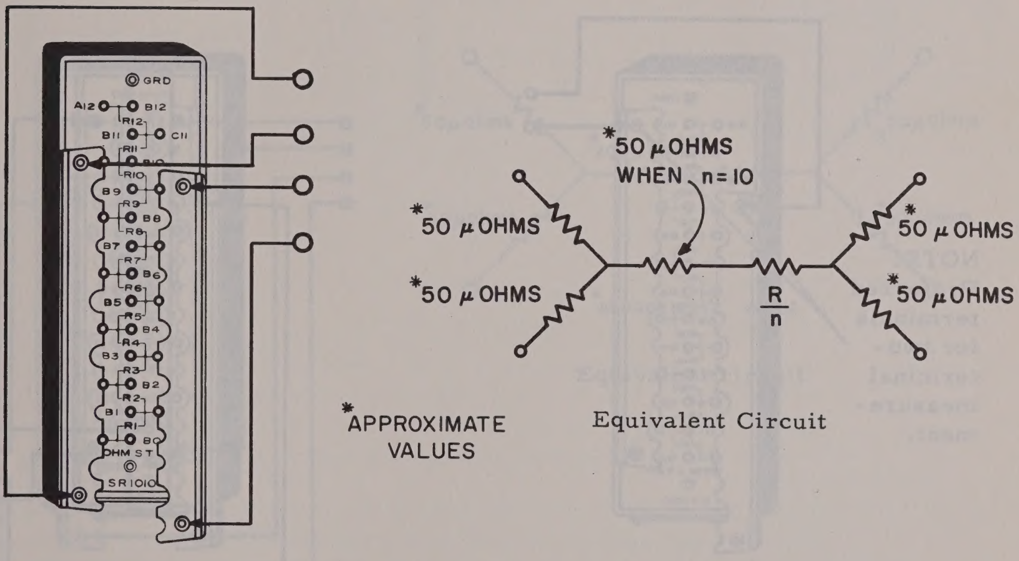
Equivalent Circuit

*APPROXIMATE VALUES

FIG. 2.2.2b

It should be noted that the resistance in series with the terminals to the compensation network is considerably higher than that in series with the terminals to the shorting bars, see Figure 2.2.2b. When connecting this paralleled group of resistors and compensating network to a bridge or ratio set care should be taken to connect these higher resistance terminals where they will least affect the accuracy of the measurement.

A simplified four-terminal parallel connection of any number of resistors can be made using only the shorting bars as shown in Figure 2.2.2c. This places a small connection resistance in series with the paralleled resistance. However, since there will be several contacts in parallel it will be a fairly stable and reproducible resistance and can be subtracted from the measured value, see Figure 2.2.2c.



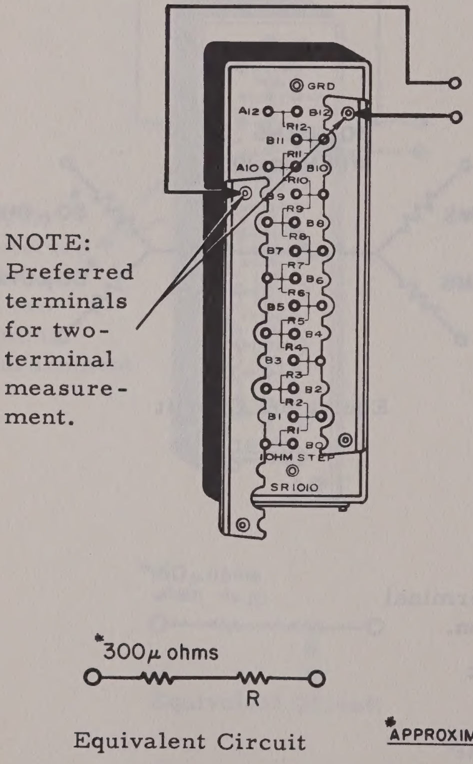
Equivalent Circuit

Simplified four-terminal parallel connection.

FIG. 2.2.2c

2.2.3 SERIES-PARALLEL GROUP OF RESISTORS

In addition to the series and parallel connections, series-parallel connections of the SR 1010 are also possible. With this method nine resistors, three parallel groups of three resistors in series, may be used to form a stable resistor equal in value to the individual resistors in the string. The ESI MODEL SB 103 SHORTING BARS can be used for this type of connection also, see Figure 2.2.3a. For individual resistors of less than one hundred ohms resistance, the paralleling leads and contact resistance may cause significant errors. These errors can be essentially eliminated by use of a special compensation network for making four-terminal series-parallel connections (ESI MODEL SPC 102 SERIES-PARALLEL COMPENSATION NETWORK). Such a network is shown connected to a SR 1010 in Figure 2.2.3b.



NOTE: Preferred terminals for two-terminal measurement.

*APPROXIMATE VALUES

FIG. 2.2.3a

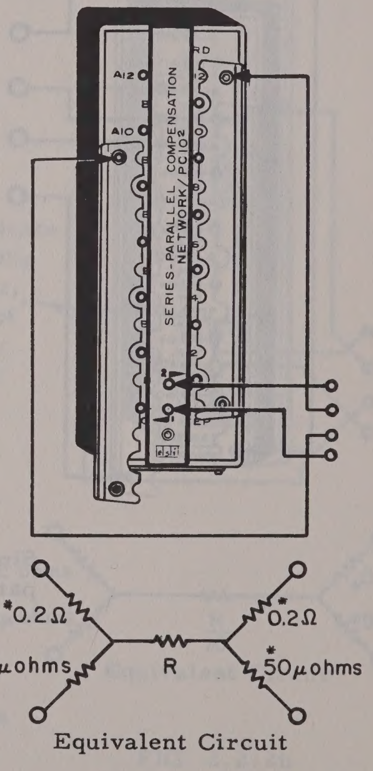
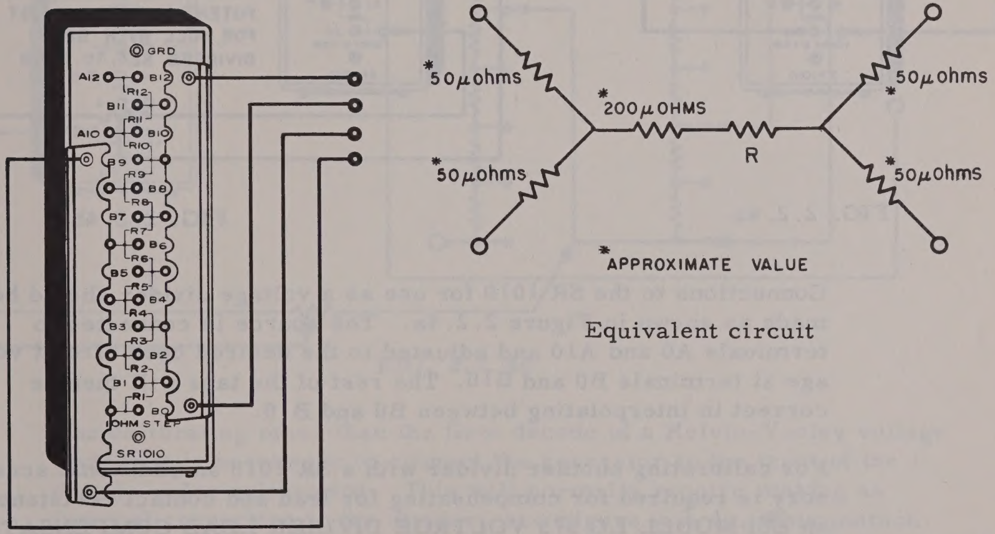


FIG. 2.2.3b

It should be noted that the resistance in series with the terminals to the compensation network is considerably higher than that in series with the terminals to the shorting bars, see Figure 2.2.3b. When connecting this paralleled group of resistors and compensating network to a bridge or ratio set care should be taken to connect these higher resistance terminals where they will least affect the accuracy of the measurement.

A simplified four-terminal series-parallel connection can be made using only the shorting bars as shown in Figure 2.2.3c. This places the connection resistance of the shorting bars in series with the series-paralleled resistance. However, since there will be several contacts in parallel it will be a fairly stable and reproducible resistance and could be subtracted from the measured value, see Figure 2.2.3c.



Equivalent circuit

Simplified four-terminal series-parallel connection.

FIG. 2.2.3c

2.2.4 DIVIDER CONNECTIONS

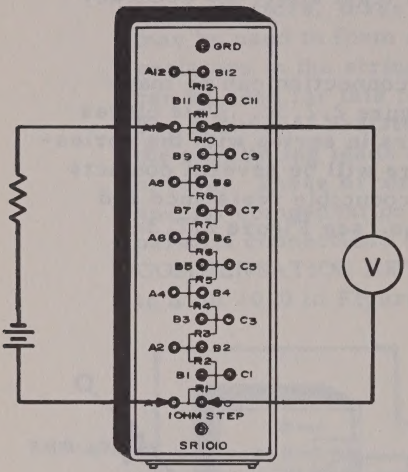


FIG. 2.2.4a

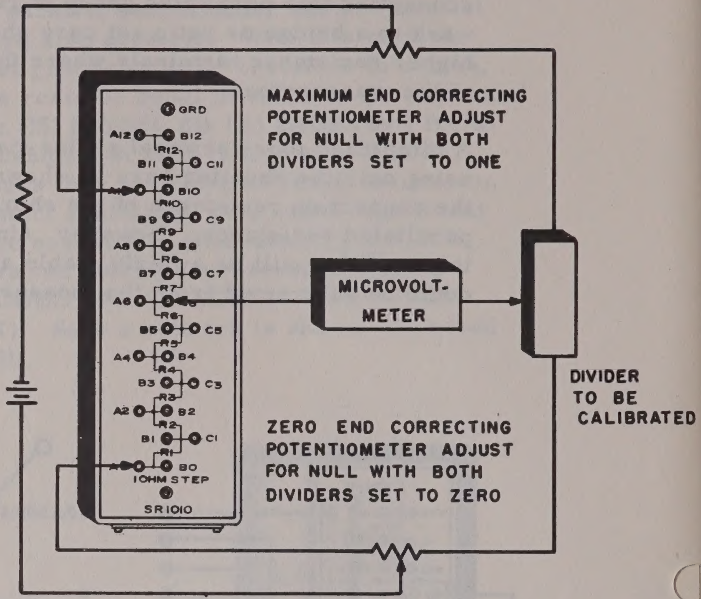

MAXIMUM END CORRECTING POTENTIOMETER ADJUST FOR NULL WITH BOTH DIVIDERS SET TO ONE
GRD
A12
B12
R12
B11
C11
R11
B10
R10
B9
C9
R9
A8
B8
R8
B7
C7
R7
A6
R6
B5
C5
R5
A4
B4
R4
B3
C3
R3
A2
B2
R2
B1
C1
R1
B0
1OHM STEP
SR1010
MICROVOLT-METER
DIVIDER TO BE CALIBRATED
ZERO END CORRECTING POTENTIOMETER ADJUST FOR NULL WITH BOTH DIVIDERS SET TO ZERO

FIG. 2.2.4b

Connections to the SR 1010 for use as a voltage divider should be made as shown in Figure 2.2.4a. The source is connected to terminals A0 and A10 and adjusted to the desired open circuit voltage at terminals B0 and B10. The rest of the taps will then be correct in interpolating between B0 and B10.

For calibrating another divider with a SR 1010 an additional accessory is required for compensating for lead and contact resistances, an ESI MODEL LC 875 VOLTAGE DIVIDER LEAD COMPENSATOR or equivalent is recommended. The lead compensator is connected between terminals B0, B10 and the input of the divider to be calibrated, see Figure 2.2.4b. With the detector connected between A0 and the maximum end of the divider to be calibrated the lead compensator is adjusted for a detector null. Change the detector connections to A10 and the minimum end of the detector to be calibrated and adjust the lead compensator for a detector null. The divider to be calibrated may then be accurately compared to the SR 1010 at integer multiples of one tenth the full scale voltage.

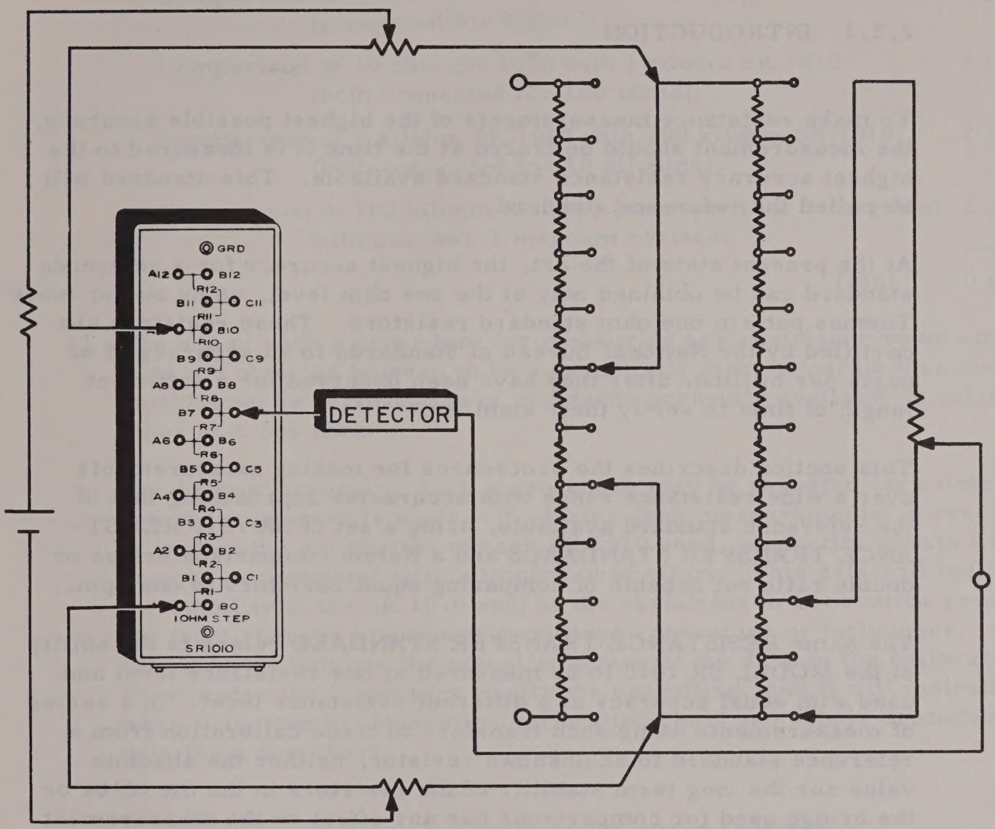


FIG. 2.2.4c

For calibrating other than the first decade of a Kelvin-Varley voltage divider it is necessary to connect the generator to the input of the decade under calibration. This will normally require making an internal connection to the divider, see Figure 2.2.4c. This method gives a complete, high accuracy calibration of the whole Kelvin-Varley divider, including all lead and switch resistances.

2.3 HIGH ACCURACY CALIBRATION TRANSFER

2.3.1 INTRODUCTION

To make resistance measurements of the highest possible accuracy, the measurement should be traced at the time it is measured to the highest accuracy resistance standard available. This standard will be called the reference standard.

At the present state of the art, the highest accuracy for a reference standard can be obtained only at the one ohm level, using one or more Thomas pattern one ohm standard resistors. These resistors are certified by the National Bureau of Standards to an accuracy of ±2 parts per million, after they have been observed for a sufficient length of time to verify their stability.

This section describes the procedures for making measurements over a wide resistance range with accuracies approaching that of the reference standard available, using a set of SR 1010 RESISTANCE TRANSFER STANDARDS and a Kelvin comparison bridge or double ratio set capable of comparing equal resistors to one ppm.

The name RESISTANCE TRANSFER STANDARD refers to the ability of the MODEL SR 1010 to be measured at one resistance level and used with equal accuracy at a different resistance level. In a series of measurements using such transfers to trace calibration from a reference standard to an unknown resistor, neither the absolute value nor the long term stability of the resistors in the SR 1010s or the bridge used for comparisons has any effect on the measurement accuracy. The burden of calibration accuracy and long-term stability is placed on the reference standard alone; the concern with the rest of the system need be only with its short-term stability during the period of a few minutes required to complete the measurement. With careful operating technique in a normal laboratory environment, each step in such a series of measurements can be accurate to one or two ppm.

In making such a chain of measurements, one of the advantages of using a set of ten resistors connected as in the SR 1010 is that a 100 to 1 transfer in resistance level can be made at each measurement, minimizing the accumulation of errors. For example, the limits of error in measuring a one megohm resistor might be assumed as follows:

Certified accuracy of 1 ohm standard	2 ppm
Comparison of 1 ohm standard with 10 ohm SR 1010 (connected for 1 ohm)	2 ppm
Comparison of 10 ohm SR 1010 with 1 kilohm SR 1010 (both connected for 100 ohms)	2 ppm
Comparison of 1 kilohm SR 1010 with 100 kilohm SR 1010 (both connected for 10 kilohms)	2 ppm
Comparison of 100 kilohm SR 1010 (connected for 1 megohm) with unknown 1 megohm resistor	2 ppm
Total	10 ppm

The use of such a procedure for measuring any resistance value other than one ohm can be seen to be substantially more accurate than could be obtained by certification of standards presently available at values other than one ohm.

For highest accuracy, such a procedure may be repeated each time a new measurement is made. If, during such measurements, a record is kept of the calibration of each SR 1010 used, a quantity of data will soon be accumulated with a minimum of effort. This data will indicate the stability of the SR 1010 and/or the variations in calibration resulting from changes in ambient conditions, operators or techniques. It can serve to indicate the actual accuracy of the data on the calibration chart under the laboratory conditions prevailing, and it will indicate when it is time to replace the calibration chart and supply dependable data for a new chart.

2.3.2 MAKING EQUAL RESISTANCE COMPARISONS

The comparison of like resistance values can be made independent of the absolute accuracy and long-term stability of the comparison bridge by using either an interchange or a substitution method. A direct-reading double ratio set, such as the ESI MODEL 240 KELVIN RATIO BRIDGE, for making four-terminal comparison measurements with a 1 ppm resolution and short-term stability, should be used for calibration transfer with SR 1010s.

The following outlines the procedure for comparing two resistors by the interchange method:

1) With the standard resistor or previously calibrated SR 1010 connected to the standard terminals of the bridge and the unknown

resistor or SR 1010 to be calibrated connected to the unknown terminals, balance the bridge and determine the deviation of the unknown from the standard. Call this reading d_1.

2) With the unknown resistor connected to the standard terminals and the standard resistor connected to the unknown terminals, balance the bridge and determine the deviation of the standard from the unknown. Call this reading d_2.

3) Calculate $\frac{d_1 - d_2}{2}$ this is the deviation of the unknown resistor from the standard resistor. To obtain the deviation of the unknown resistor from nominal value, add to this calculated value the deviation of the standard resistor from nominal value.

To compare two resistors by the substitution method, connect to the standard terminals of the bridge a working standard resistor of the required value and make two measurements, the first with the standard resistor or previously calibrated SR 1010 connected to the unknown terminals, and the second with the unknown resistor or SR 1010 to be calibrated connected to the unknown terminals. The difference between these two readings will be the difference between the two resistors.

The substitution method is particularly convenient when either the working standard or the bridge ratio can be adjusted to make the bridge deviation dial read deviation from nominal value directly. The procedure is then modified so that when the known resistor is connected to the unknown terminals, the deviation dial is adjusted to its known deviation from nominal value and the working standard or ratio calibration adjustment is used to balance the bridge. When the known resistor is disconnected and the unknown connected to the unknown terminals, the deviation dial at balance will indicate directly the deviation of the unknown resistor from nominal value.

In a series of calibration transfer measurements in which the unknown resistance in one comparison and the known resistance in the next consist of the same group of resistors differently connected, the deviation reading in the first comparison becomes the initial deviation setting for the next measurement. Thus the dial setting serves as a mechanical memory and indicates the actual deviation value through the whole series of measurements, including the final reading on the unknown resistor.

The ESI MODEL RS 925 DECADE RESISTANCE STANDARD makes an excellent adjustable, four-terminal working standard with a 1 ppm resolution at settings of 100 ohms and above. The 100 ohm setting of the RS 925 can be used for measurements by the substitution method at 1 and 10 ohms if the bridge has ratios of 10 to 1 and 100 to 1. The ESI MODEL 240 KELVIN RATIO BRIDGE provides these ratios, though at somewhat reduced accuracy as a result of sensitivity to lead resistance errors in the connection to the unknown. To retain the full accuracy of the 1 to 1 ratio of the Model 240 bridge for measurements at 1 and 10 ohms, another SR 1010 can be used as a fixed working standard -- use the 1 ohm box as a working standard when calibrating the 10 ohm box, and vice versa.

2.3.3 USING A CERTIFIED RESISTANCE STANDARD

It is necessary to begin any chain of transfer measurements with a very accurately known and highly stable standard resistor. The Thomas pattern one ohm resistor is such a resistor and is recommended for this purpose. These resistors are commercially available and many of them are certified to an accuracy of ±2 ppm per year. In high-accuracy calibration transfer measurements, the Thomas pattern one ohm resistor is used to calibrate the nine-resistor series-parallel configuration of the 1 ohm SR 1010 or the ten-resistor parallel configuration of the 10 ohm SR 1010.

The following suggestions will aid in making measurements at the one ohm level with maximum accuracy:

1) Operate the Thomas pattern resistor in oil in order to minimize its temperature rise with power dissipation and to allow accurate measurement of the resistor temperature. If accurate temperature coefficient data is available for the resistor (α and β terms), a small unstirred pot of oil at room temperature is quite adequate. Measure the oil temperature to an accuracy of ±0.2°C and calculate the value of the resistor at this temperature.

2) To avoid internal heating of the standard and the SR 1010, use reduced input power to the bridge for the initial balance adjustment, then increase power to approximately one half watt (0.5 amp through standard and unknown) for only a few seconds, to make the final accurate balance adjustment. Both the Thomas pattern resistor and the SR 1010 will typically remain constant within 1 ppm for approximately 10 seconds at this power level.

3) When using 1 ohm and 10 ohm SR 1010 boxes, complete their comparison with the reference standard and their use in calibrating higher value SR 1010s in as short a time as possible, in order to

keep all the measurements at as nearly the same temperature as possible. The exact temperature of an SR 1010 in calibration transfer is unimportant, but its temperature must remain sufficiently constant throughout the procedure. This is particularly important with the 1 and 10 ohm boxes, since they have higher temperature coefficients then the higher value boxes.

In changing the connections to the SR 1010, avoid unnecessary handling, in order to minimize temperature changes.

2.3.4 CALIBRATION TRANSFER BETWEEN SR 1010 BOXES

In calibration transfer measurements, the three most commonly used connection configurations for the SR 1010s are ten resistors in parallel, nine resistors in series-parallel, and ten resistors in series, yielding resistance values of 0.1, 1 and 10 times the individual resistor value. It is always preferable to use one of these groups of resistors in preference to any single resistor, in order to minimize temperature rise with internal heating and to take advantage of averaging of temperature coefficients of the various resistors in the box.

The basic absolute resistance calibration of an SR 1010 box is accomplished by accurately measuring any one of these three connection configuration. Once the reference standard or a previously calibrated SR 1010 has been used to calibrate one of these three configuration for a box, the values for all other resistor configurations are obtained by calculation using this value with selected measurements of the resistors in the same box relative to one another or relative to the nine-resistor series-parallel configuration having the same resistance value.

For 1 ppm accuracy in calibrating or using the ten resistor parallel and nine resistor series-parallel configurations, the PC 101 and SPC 102 compensation networks must be used with the 1 ohm and 10 ohm boxes, and with the 100 ohm box unless a correction is made for terminal resistance. The simplified four-terminal connection using the SB 103 shorting bar pair alone is adequate for SR 1010s having values of 1 kilohm per step or higher (see Section 2.2).

The recommended sequence for calibration transfer to the various SR 1010 boxes is as follows:

SR 1010 (ohms/step)	Connection	Number of Resistors	Compared to
1	Series-Parallel	9	One Ohm Reference Standard
10	Parallel	10	
100	Series-Parallel	9	10 ohm per step SR 1010 ten resistors in series
1K	Parallel	10	
10K	Series-parallel	9	1 kilohm per step SR 1010 ten resistors in series
100K	Parallel	10	

2.3.5 CALIBRATION TRANSFER BETWEEN PRINCIPAL CONFIGURATIONS

The majority of calibration transfer applications require the use of only the three principal resistance configurations for the SR 1010 boxes; for these measurements, the individual resistors need never be calibrated. This is the key to both the high accuracy and the extreme simplicity of this transfer technique.

The basic rule relating resistor configurations is that all configurations which use the same group of resistors and distribute the power equally among them have the same deviation from the nominal values for the configurations; this deviation is equal to the average of the deviations of the individual resistors in the group from their nominal value. (This is true to one part in 10^9 for the resistor matching used in SR 1010s).

Thus ten resistors in series will have exactly 100 times the resistance of the same ten resistors in parallel, or nine resistors in series-parallel will have exactly nine times their resistance in parallel, or exactly one ninth of their resistance in series. Thus when a resistor group is calibrated in one configuration and exactly the same group used in another configuration at a different resistance level, no further measurements are necessary and no calculations are required.

To transfer calibration between the ten resistor group and the nine resistor group, the difference between the tenth resistor and the nine-resistor series-parallel configuration must be measured* in order to calculate the average diviations of the two groups.

The formula relating the average deviation of one group to that of the other, to calculate one when the other has been measured, is:

$$d^9_{av} - d^{10}_{av} = 0.1\ (d^9_{av} - d_{10})$$

in which:

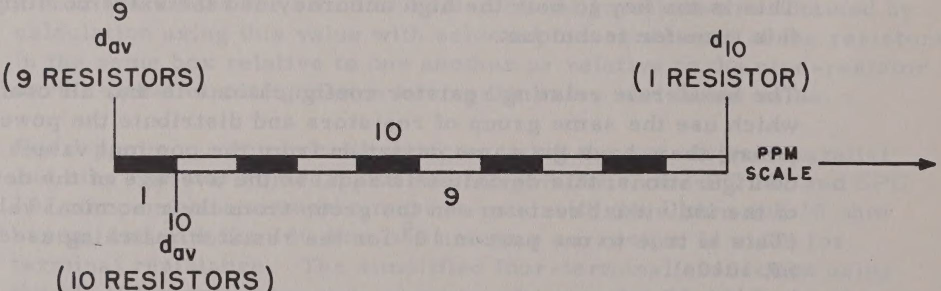
d^9_{av} is the average deviation of the nine resistor group from nominal.

d^{10}_{av} is the average deviation of the ten resistor group from nominal.

d_{10} is the deviation of the tenth resistor from nominal.

$(d^9_{av} - d_{10})$ is the measured difference between the nine-resistor series-parallel configuration and the tenth resistor.

This formula can be visualized as a weighted average on a diagram as follows:



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*For box values requiring the use of the compensation networks, this measurement must be made by the substitution method, rather than the interchange method, since the network must be removed to connect to the tenth resistor for measurement.

Note that the measured difference is multiplied by one tenth; thus if the measurement by the substitution method is accurate to 1 or 2 ppm, the calculated difference between the groups will be correct to 0.1 or 0.2 ppm, which can be considered negligible compared with the accuracy to which the measured group is known.

2.3.6 CALIBRATION TRANSFER TO INDIVIDUAL RESISTORS

To calibrate the individual resistors of a SR 1010 it is recommended that the deviation from nominal of a series or parallel group of ten, or a series-parallel group of nine be determined as accurately as possible by comparison to a known reference standard. Next each of the individual resistors must be compared to a stable working standard to determine their deviations relative to one another. From these relative deviations the average deviation for the group first measured is calculated. The difference of this measured deviation from nominal minus the calcuated average deviation is added to each of the individual deviations to determine the deviation from nominal of the individual resistors.

A step by step procedure for calibrating the individual resistors of a complete set of SR 1010s is given in Section 4.3.1 and 4.3.2 and is exemplified in Section 4.3.3.

2.3.7 CALIBRATION OF AN SR 1010 AS A TEN-STEP DIVIDER

Since ratio measurements do not depend upon any absolute resistance standard, no reference standard of resistance is required to calibrate an SR 1010 as a divider. The procedure for calibrating an SR 1010 as a divider with ten equal steps is as follows:

1) Connect a stable working standard, whose nominal value is equal to that of the individual resistors of the SR 1010 to be calibrated, to the standard terminals of the bridge.

This standard may be ten resistors in series (or parallel) of the SR 1010 whose resistance per step is one tenth (or ten times) that of the SR 1010 to be calibrated.

2) Measure d_n, the deviation of each of the first ten resistors in the string from that of the standard resistor.

The calibration of the bridge or the accuracy of the working standard need not be considered, only their short term stability is of importance.

3) Calculate the average deviation, d_{av}^{10}, of the ten measured deviations, d_n.

$$d_{av}^{10} = 0.1 \sum_{n=1}^{10} d_n$$

4) Subtract the average deviation, d_{av}, from each deviation d_n.

$$(d_n - d_{av}^{10})$$

5) Sum these differences to each tap and divide by ten to get the linearity deviation at the tap.

$$L_r = 0.1 \sum_{n=1}^{n=r} (d_n - d_{av}^{10})$$

where:

L_r is the linearity deviation at the rth tap. Linearity deviation is defined as the difference between actual tap value and nominal tap value expressed as a proportional part of full scale.

A sample tabular calculation of steps 3), 4), and 5) will be found in Figure 2.1.3.

SECTION III

THEORY

3.1 JUNCTION RESISTANCE EFFECTS

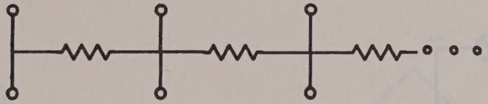


FIG. 3.1a

The series configuration of the SR 1010 TRANSFER STANDARD is shown in Figure 3.1a. The four-terminal resistors can be measured individually or in any series combination. If the measured series resistance is to be equal to the sum of the individual resistor measurements, the junctions must have zero four-terminal resistance. This junction transresistance is zero if a current source connected to any two of the four junction terminals produces zero voltage difference between the other two terminals.

In practice, the junctions do have some transresistance. It is possible to make the resistance very low (much less than 1 microhm) by proper design. For instance, if four terminals are connected to a plane sheet of metal in the configuration shown in Figure 3.1b, two of the terminals will always be on an equipotential line if a current source is connected to the other two terminals.

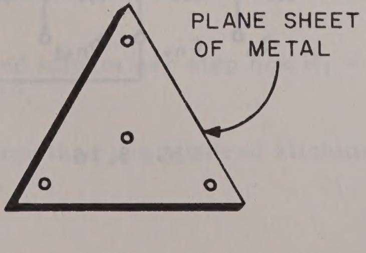


FIG. 3.1b

The tests for a four-terminal point junction are shown in Figure 3.1c. The meter voltages divided by the generator currents are the transresistances for the two connections shown. A third transresistance, shown in Figure 3.1d need not be measured, since it is always equal to the difference between the other two (note that each reading in Figure 3.1c may be either positive or negative; keep this sign when subtracting to calculate third transresistance).

These three transresistances represent the greatest possible resistance measurement error. For the junction in the SR 1010 each of these three resistances is less than 0.5 microhm, causing much less than one ppm error for even a one ohm per step box.

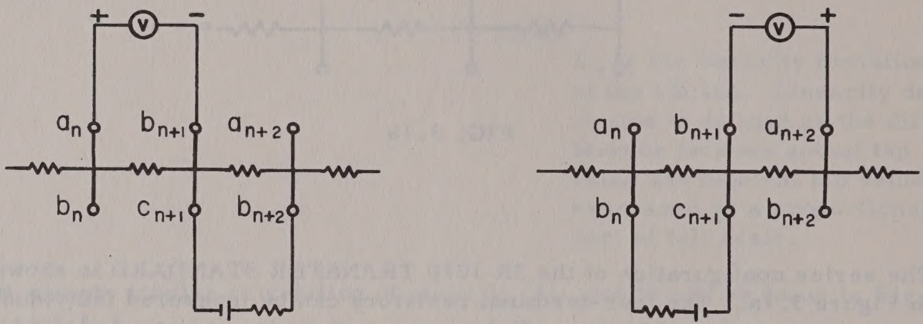


FIG. 3.1c

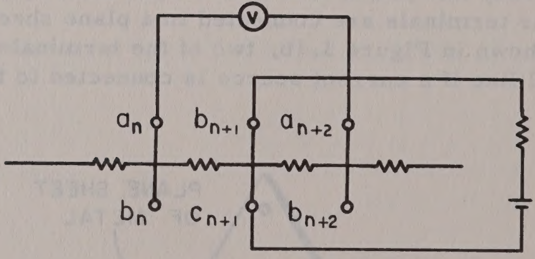


FIG. 3.1d

3.2 INSULATION RESISTANCE EFFECTS

The leakage resistance of the SR 1010 to its case is in excess of 10^{12} ohms. For worst case conditions (twelve one hundred kilohm resistors in series with one end of the SR 1010 tied to its case) the error due to shunt resistance will be less than 1.2 ppm.

If a three terminal measurement is made (the case being the third terminal) and again worst case conditions assumed (twelve resistors in series with all leakage being concentrated from the center point of the series string) the following wye-delta transformation is necessary to determine the resulting error.

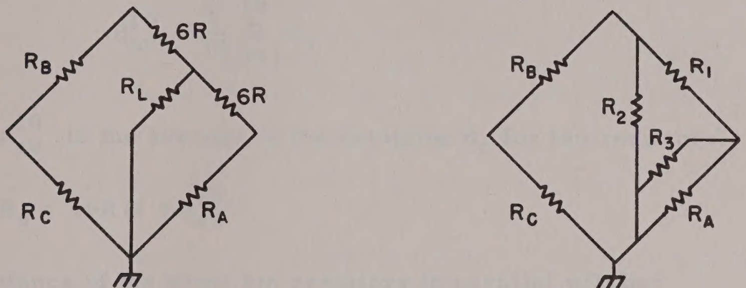


FIG. 3.2

where:

R_A, R_B and R_C are the ratio arms of the bridge.
R is the resistance per step of the SR 1010.
R_L is the leakage resistance from the SR 1010 to its case.

$$R_1 = \frac{36R^2}{R_L} + 12R = 12R(1 + \frac{3R}{R_L})$$

R_2 is across the generator or detector so can be neglected.

$$R_3 = 2R_L + 6R$$

For a one hundred kilohm per step box $R_1 = 12R\,(1 + 0.3 \text{ ppm})$ and $R_3 = 2 \times 10^{12}$.

If R_A is no greater than one hundred kilohms the error will not exceed 0.3 ppm.

Since leakage resistance will lower the measured resistance in a two-terminal measurement and increase it in a three-terminal measurement the actual resistance must lie between these two values. This fact can be used as a check to determine the magnitude of the error due to leakage resistance.

3.3 BASIC TRANSFER ACCURACY

To make transfer measurements which do not depend on the absolute accuracy of the transfer standard but only on its short term stability, it is necessary to assume that ten resistors in parallel are exactly equal to one one hundredth of the same ten resistors in series. To see how valid this assumption is let R be the nominal value of the individual resistors and d_n the deviation from nominal of this nth resistor. The value of the nth resistor will then be $R_n = R(1 + d_n)$. The value of the ten resistors in series will be:

$$R_s = \sum_{n=1}^{10} R\,(1 + d_n) = 10R\,(1 + \frac{1}{10}\sum_{n=1}^{10} d_n)$$

$$d_{av}^{10} = \frac{1}{10}\sum_{n=1}^{10} d_n$$

where: d_{av}^{10} is the average of the deviation d_n for ten resistors.

$$R_s = 10R\,(1 + d_{av}^{10})$$

The resistance of the same ten resistors in parallel will be:

$$R_p = \frac{1}{\displaystyle\sum_{n=1}^{10} \frac{1}{R\,(1 + d_n)}}$$

$$\frac{1}{R(1 + d_n)} = \frac{1}{R}\,(1 - d_n + d_n^{\,2} - d_n^{\,3} \ldots\ldots)$$

$$R_p = \frac{1}{\displaystyle\sum_{n=1}^{10} \frac{1}{R}(1 - d_n + d_n^{\,2} \ldots\ldots)}$$

$$R_p = \frac{R}{10}\;\frac{1}{1 + \displaystyle\frac{1}{10}\sum_{n=1}^{10} (-d_n + d_n^{\,2} \ldots\ldots)}$$

$$R_p = \frac{R}{10}\left(1 + \frac{1}{10}\sum_{n=1}^{10} d_n - \frac{1}{10}\sum_{n=1}^{10} d_n^{2} \ldots\ldots\right)$$

$$R_p = \frac{R}{10}\left(1 + d_{av}^{10} - \frac{1}{10}\sum_{n=1}^{10} d_n^{2} \ldots\ldots\right)$$

$$R_p \approx \frac{R}{10}\left(1 + d_{av}^{10}\right)$$

The assumption being that $\frac{1}{10}\sum_{n=1}^{10} d_n^{2}$ is negligible. Since d_n maximum for the SR 1010 is less than 100 ppm d_n^{2} will be less than 0.01 ppm which can be neglected, thus the original assumption is quite valid. A similar analysis can be made for the series-parallel connection or any other configuration in which the power divides equally among the resistors.

3.4 FOUR-TERMINAL PARALLELING

The parallel connection of ten four-terminal resistors is shown in Figure 3.4a.

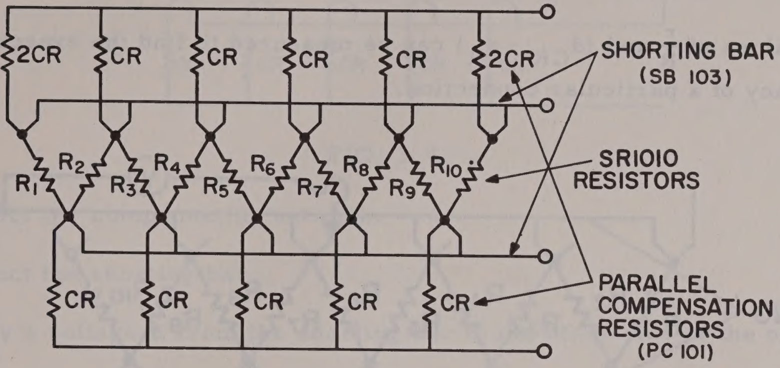


FIG. 3.4a

FIG. 3.4a TEN FOUR-TERMINAL RESISTORS IN PARALLEL

The shorting bar resistance and the resistance from the junctions to the shorting bars should be small. The parallel-compensation resistors should be large compared to the uncertainty in the contact resistances when they are connected and should be proportional to the resistance of the SR 1010 resistors. The two parallel-compensation resistors on the ends are double the others because they connect to one build-up resistor instead of two in parallel.

When several nominally equal resistors are connected in parallel the connection accuracy can be analyzed by assuming all of the compensation resistors except one are equal, and that all of the bus bar resistances except one are zero. At the same time all of the resistors being connected are assumed to be perfect except one. The three imperfect resistors all meet at one of the junctions. Since small first order error effects add linearly the results of this analysis can be extended to determine the connection accuracy. The connection uncertainty is less than:

$$\pm 2\left(\frac{r}{R}\right)(d_{CR} - d_R)$$

where:

r is the greatest bus bar resistance

R is the nominal value of resistors being parallel connected

$(d_{CR} - d_R)$ is the greatest bridge unbalance in terms of resistance deviations of the compensation resistors and the resistors being connected

The values of $\frac{r}{R}$ and $(d_{CR} - d_R)$ can be measured to find the expected accuracy of a particular connection.

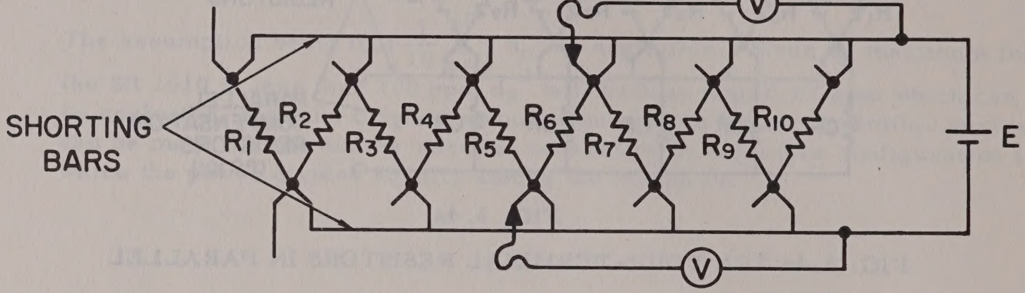


FIG. 3.4b

Connect the shorting bars.

Measure voltage from a point on the bars to the unused terminals, this is the voltage to the junction of adjacent resistors.

Find the maximum difference of values V for each bar.

Use the greatest V difference to calculate $(\frac{r}{R})_{max}$

$$\text{for } r \ll R \qquad \frac{V_{max} - V_{min}}{E} \approx \left(\frac{r}{R}\right)_{max}$$

The value of $\frac{r}{R}$ can be found by measuring the voltage drops from a point on the bus bars to the junction of adjacent resistors, shown in Figure 3.4b.

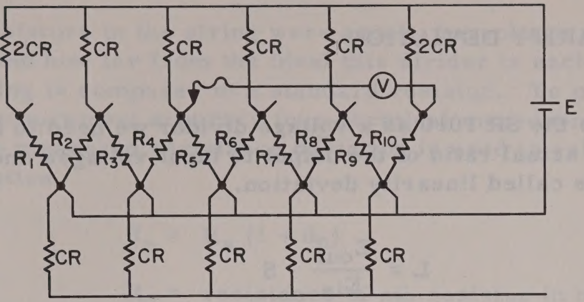


FIG. 3.4c

Connect the compensating network.

Connect the shorting bar.

Supply a voltage E from the shorting bar to the other side of the network.

Measure the voltage V from one unused shorting bar terminal to each of the others.

Change the shorting bar to the other side and repeat.

Find the maximum voltage difference $(V_{max} - V_{min})$ between terminals.

Calculate $(d_{CR} - d_R)_{max}$

$$\left(\frac{V_{max} - V_{min}}{E}\right)\left(2 + \frac{2CR}{R} + \frac{R}{R}\right) = (d_{CR} - d_R)_{max}$$

The bridge unbalance can be measured as shown in Figure 3.4c. The measured values of $(\frac{r}{R})_{max}$ and $(d_{CR} - d_R)_{max}$ can be multiplied together and doubled to give an upper bound of the connection error. This usually includes a very substantial safety factor. The same technique can be used in the series-parallel case.

3.5 LINEARITY DEVIATION

To calibrate the SR 1010 as a voltage divider we need to know the difference between the actual ratio of the output to input voltages and the setting. This difference is called linearity deviation.

$$L = \frac{E_{out}}{E_{in}} - S$$

L - linearity deviation

E_{in} - actual input voltage

E_{out} - actual output voltage

S - divider setting

Since the voltage and resistance divide proportionately, the linearity deviation can be found by a precision comparison of the resistors in the divider string. By using ten resistors of the SR 1010 in the divider string, the output can be set to integral multiples of a tenth the input voltage. The linearity deviation for this divider can be written as:

$$L = \frac{\sum_{n=1}^{10S} R_n}{\sum_{n=1}^{10} R_n} - S$$

L - linearity deviation

R_n - resistance of nth resistor

$\sum_{n=1}^{10S} R_n$ - resistance from COM to OUT in ohms

$\sum_{n=1}^{10} R_n$ - total input resistance in ohms

S - divider setting

If all of the resistors in the string were equal, the voltage would divide equally. To find how far from the ideal this divider is each resistor, R_n, of the string is compared to a standard resistor. To maintain the ultimate in measurement accuracy four-terminal measurements should be made. The measured resistance deviation is used to calculate the linearity deviation.

$$R_n = R_s (1 + d_n)$$

R_n = resistance of nth resistor in ohms

R_s = resistance of standard resistor in ohms

d_n = per unit deviation of R_n from R_s

This leads to the following expression for linearity deviation:

$$L = \frac{\sum\limits_{n=1}^{10S} (1 + d_n)}{\sum\limits_{n=1}^{10} (1 + d_n)} - S$$

The precise value of the standard resistor is unimportant since it is canceled out of the equation, thus anyone of the resistors of the string can be used as the standard resistor. To simplify calculations the equation for linearity deviation can be modified by first defining the average deviation as

$d_{av}^{10} = 0.1 \sum\limits_{n=1}^{10} d_n$ and then assuming d_{av}^{10} is much smaller than one. The

equation for linearity deviation can then be expressed as follows:

$$L = 0.1 \sum_{n=1}^{10S} (d_n - d_{av}^{10})$$

SECTION IV

CALIBRATION

4.1 INTRODUCTION

This section provides MODEL SR 1010 TRANSFER STANDARD calibration procedures for those that have the necessary facilities. Calibration should be performed in a laboratory environment. If this is not possible return the instrument to the factory or an authorized service facility for calibration.

Calibration of the SR 1010 for immediate use at highest accuracy is a part of the normal operating procedure, the detailed procedures are given in Section II. This section will contain comments related to systematic or routine calibration, and to special tests. These procedures will verify the performance of the whole SR 1010 calibration system, including the SB 103 SHORTING BARS, the PC 101 PARALLEL COMPENSATION NETWORK and SPC 102 SERIES-PARALLEL COMPENSATION NETWORK.

4.2 EQUIPMENT REQUIRED

1) Resistance reference standard: Preferably a Thomas pattern one ohm certified to at least 5 ppm.

2) Oil bath: Temperature regulated at certificate temperature of resistance standard or if temperature coefficient of the standard is known a thermometer with 0.1°C steps for accurately determining the temperature of the oil bath can be used.

3) Comparison bridge: One to one Kelvin comparison bridge or direct reading ratio set for making four-terminal resistance comparisons. The resolution of the bridge and sensitivity of the associated detector should be sufficient to resolve 1 ppm deviations of the unknown from the standard for resistances from 1 ohm to 1 megohm. The short term stability should be better than 1 ppm. (ESI MODEL 240 KELVIN RATIO BRIDGE or equivalent).

4) Environmental requirements:

Temperature: 23°C ±1°C
Relative humidity: less than 60%, approximately 50%

5) Accessories:

Shorting bars: paralleling straps for connecting ten resistors in parallel or nine in series-parallel. (ESI MODEL SB 103 or equivalent).
Compensation networks: networks for making four-terminal parallel and series-parallel connections. (ESI MODELS PC 101 and SPC 102 or equivalent).

6) Microvoltmeter: With an input resistance of at least ten kilohms and on which less than one microvolt can be observed. (ESI MODEL 800 DC GENERATOR-DETECTOR recommended). A galvonometer can be used instead but it may be necessary to calibrate its sensitivity.

7) Current source: Approximately one amp current source; generator of ESI MODEL 800 can be used.

8) Voltage source: Approximately one hundred volt source; generator of ESI MODEL 800 can be used.

4.3 SEQUENCE OF CALIBRATION

4.3.1 CALIBRATION OF AVERAGE OF RESISTOR GROUPS

1)	Connect the Thomas pattern one ohm standard resistor to the standard terminals of the comparison bridge.	See Figure 4.3.1a.
2)	Connect nine resistors of the one ohm per step box in series-parallel using the series-parallel compensation network.	See Section 2.2.3 for proper series-parallel connections.
3)	Connect these nine series-parallel resistors to the unknown terminals of the bridge.	See Figure 4.3.1a.

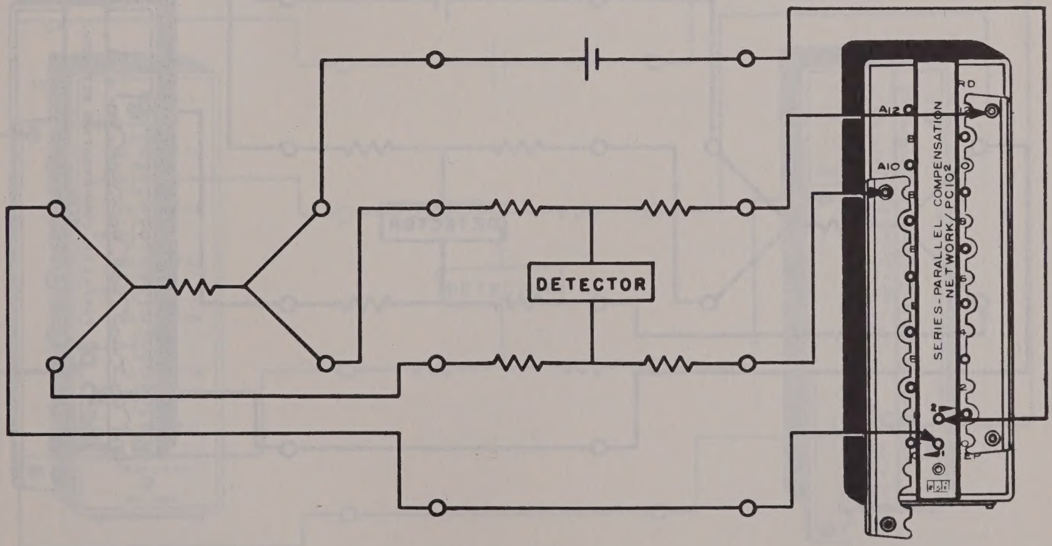


FIG. 4.3.1a

4)	Compare the two resistances by the interchange method described in Section 2.3.2, also see the suggestions given in Section 2.3.3.	This gives the deviation of the one ohm per step SR 1010 from the standard, to find its deviation from nominal add to this the deviation from nominal of the one ohm standard.
5)	Connect the Thomas pattern one ohm standard to the standard terminals of the bridge.	See Figure 4.3.1b.
6)	Connect ten resistors of the ten ohm per step box in parallel using the parallel compensation network and shorting bars.	See Section 2.2.2 for proper parallel connections.

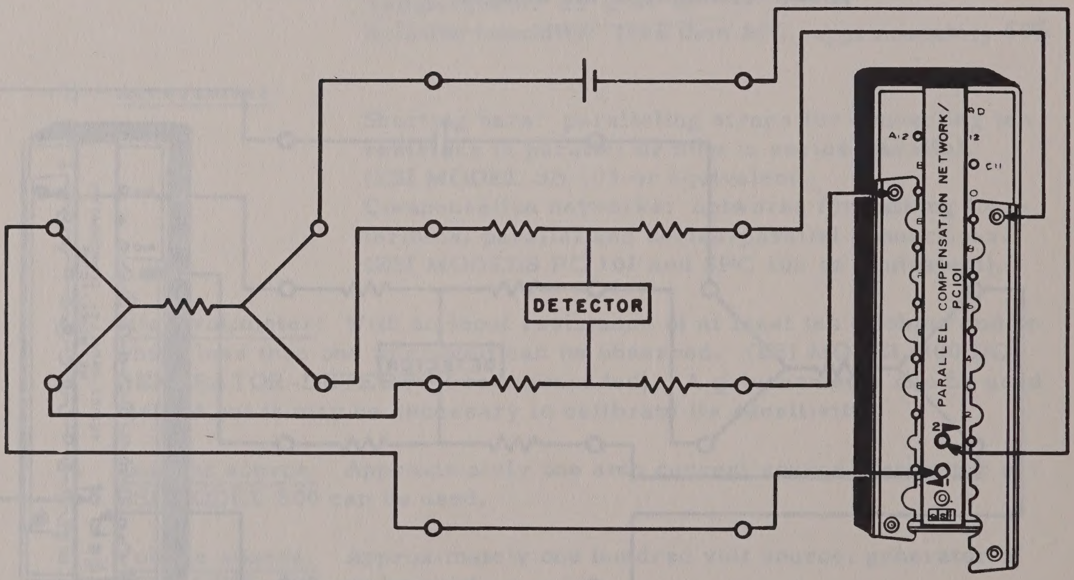


FIG. 4.3.1b

7)	Connect the ten parallel resistors of the ten ohm per step box to the unknown terminals of the bridge.	See Figure 4.3.1b.
8)	Compare the two resistances by the interchange method described in Section 2.3.2.	This gives the deviation of the ten ohm per step SR 1010 from the standard, to find its deviation from nominal add to this the deviation from nominal of the one ohm standard.
9)	Remove the parallel straps from the ten ohm per step box and connect the same ten resistors in series to the standard terminals of the bridge.	See Figure 4.3.1c.

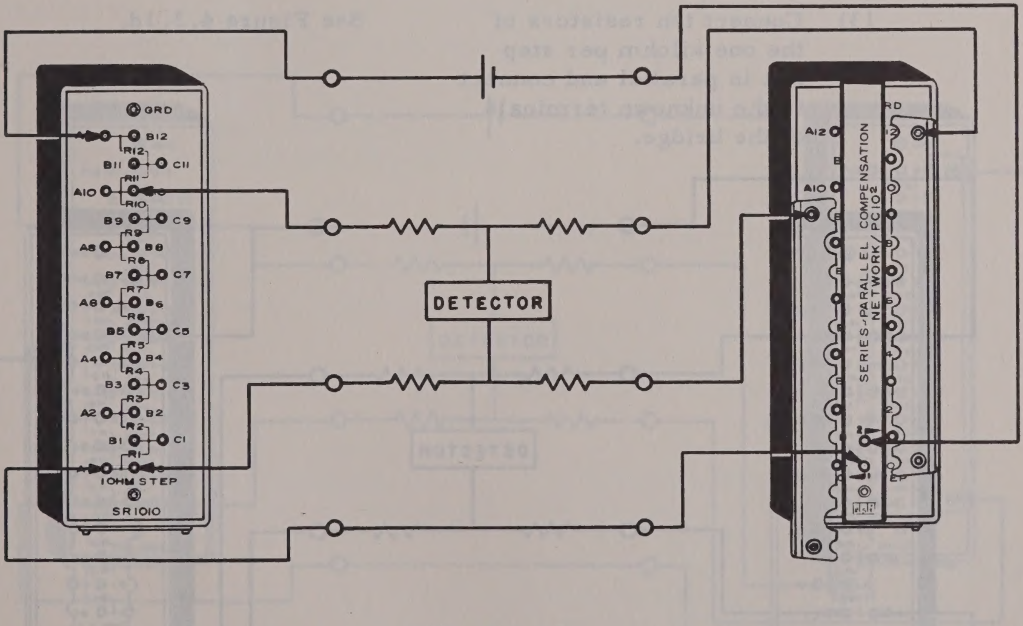


FIG. 4.3.1c

10) Connect nine resistors of the 100 ohm per step box in series-parallel using the compensation network and connect to the unknown terminals of the bridge.

See Section 2.2.3 for proper series-parallel connections and Figure 4.3.1c for connections to bridge.

11) Compare the two resistances by the interchange method described in Section 2.3.2.

This gives the deviation of the one hundred ohm per step box from the ten ohm per step box, to find its deviation from nominal add to this the deviation from nominal of the ten ohm per step box as determined in step 8 above.

12) Connect the ten series connected resistors of the ten ohm per step box to the standard terminals of the bridge.

See Figure 4.3.1d.

13) Connect ten resistors of the one kilohm per step box in parallel and connect to the unknown terminals of the bridge.

See Figure 4.3.1d.

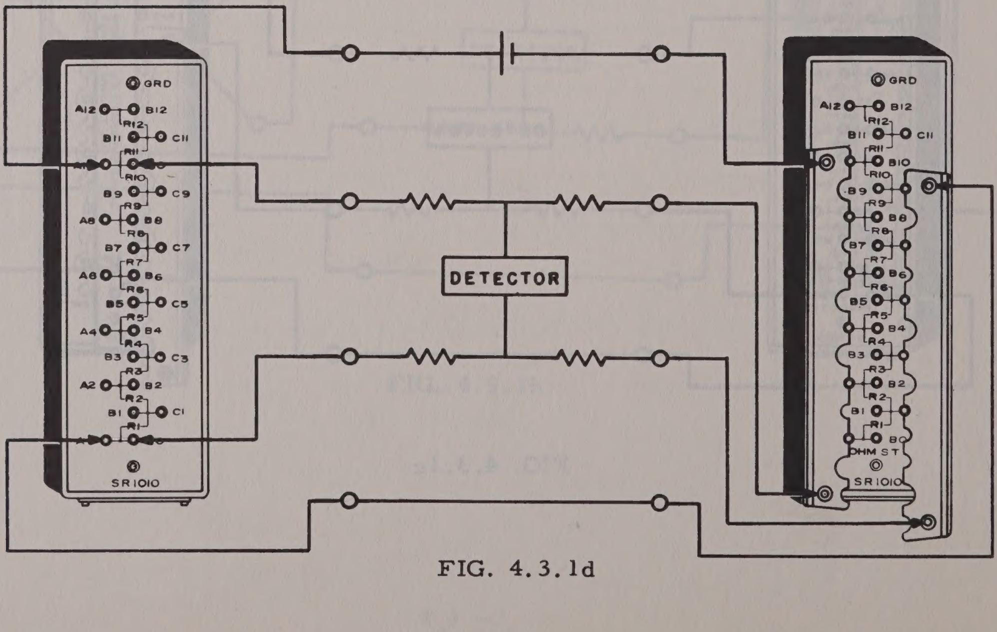


FIG. 4.3.1d

14)	Compare the two resistances by the interchange method described in Section 2.3.2.	This gives the deviation of the one kilohm per step box from the ten ohm per step box, to find its deviation from nominal add to this the deviation from nominal of the ten ohm per step box as determined in step 8 above.
15)	Remove the parallel straps from the one kilohm per step box and connect the same ten resistors in series to the standard terminals of the bridge.	See Figure 4.3.1e.
16)	Connect nine resistors of the ten kilohm per step box in series-parallel and connect to the unknown terminals of the bridge.	See Figure 4.3.1e.

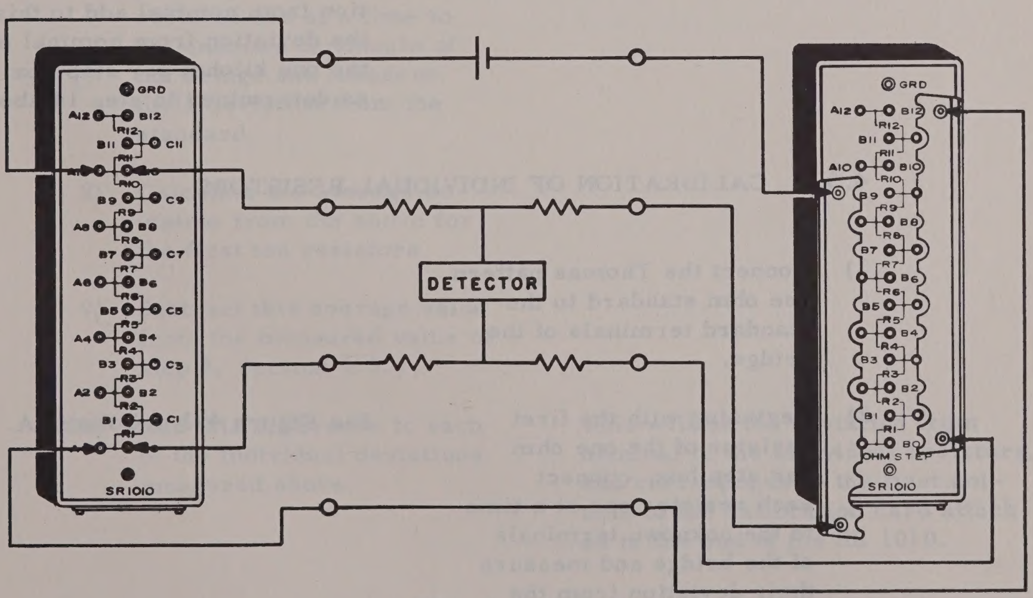


FIG. 4.3.1e

17)	Compare the two resistances by the interchange method described in Section 2.3.2.	This gives the deviation of the ten kilohm per step box from the one kilohm per step box, to find its deviation from nominal add to this the deviation from nominal of the one kilohm per step box as determined in step 14 above.
18)	Connect the ten series connected one kilohm resistors to the standard terminals of the bridge.	See Figure 4.3.1d.
19)	Connect ten resistors of the one hundred kilohm per step box in parallel and connect to the unknown terminals of the bridge.	See Figure 4.3.1d.
20)	Compare the two resistances by the interchange method described in Section 2.3.2.	This gives the deviation of the one hundred kilohm per step box from the one kilohm per step box, to find its deviation from nominal add to this the deviation from nominal of the one kilohm per step box as determined in step 14 above.

4.3.2 CALIBRATION OF INDIVIDUAL RESISTORS

1)	Connect the Thomas pattern one ohm standard to the standard terminals of the bridge.	
2)	Beginning with the first resistor of the one ohm per step box, connect each resistor one at a time to the unknown terminals of the bridge and measure their deviation from the standard.	See Figure 4.3.3 Column A.

3)	Calculate the average deviation, from the above, for the first nine resistors.	See Section 4.3.3.
4)	Subtract this average value from the measured value of step 4, Section 4.3.1.	
5)	Add this difference to each of the individual deviations measured above.	This will be the deviation from nominal of the individual resistors, and corresponds to the first column of the calibration card attached to the end of the SR 1010.
6)	Connect the first ten resistors of the one ohm per step box in series to the standard terminals of the bridge.	
7)	Beginning with the first resistor of the ten ohm per step box, connect each resistor one at a time to the unknown terminals of the bridge and measure their deviation from the standard.	
8)	Calculate the average deviation from the above for the first ten resistors.	
9)	Subtract this average value from the measured value of step 8, Section 4.3.1.	
10)	Add this difference to each of the individual deviations measured above.	This will be the deviation from nominal of the individual resistors, and corresponds to the first column of the calibration card attached to the end of the SR 1010.

11) Connect the first ten resistors of the ten ohm per step box in series to the standard terminals of the bridge.

12) Beginning with the first resistor of the one hundred ohm per step box, connect each resistor one at a time to the unknown terminals of the bridge and measure their deviation from the standard.

13) Calculate the average deviation from the above for the first nine resistors.

14) Subtract this average value from the measured value of step 11, Section 4.3.1.

15) Add this difference to each of the individual deviations measured above.

This will be the deviation from nominal of the individual resistors, and corresponds to the first column of the calibration card attached to the end of the SR 1010.

16) Connect the first ten resistors of the one hundred ohm per step box in series to the standard terminals of the bridge.

17) Beginning with the first resistor of the one kilohm per step box, connect each resistor one at a time to the unknown terminals of the bridge and measure their deviation from the standard.

18) Calculate the average deviation from the above for the first ten resistors.

19) Subtract this average value from the measured value of step 14, Section 4.3.1.

20) Add this difference to each of the individual deviations measured above.

This will be the deviation from nominal of the individual resistors, and corresponds to the first column of the calibration card attached to the end of the SR 1010.

21) Connect the first ten resistors of the one kilohm per step box in series to the standard terminals of the bridge.

22) Beginning with the first resistor of the ten kilohm per step box, connect each resistor one at a time to the unknown terminals of the bridge and measure their deviation from the standard.

23) Calculate the average deviation from the above for the first nine resistors.

24) Subtract this average value from the measured value of step 17, Section 4.3.1.

25) Add this difference to each of the individual deviations measured above.

This will be the deviation from nominal of the individual resistors, and corresponds to the first column of the calibration card attached to the end of the SR 1010.

26) Connect the first ten resistors of the ten kilohm per step box in series to the standard terminals of the bridge.

27) Beginning with the first resistor of the one hundred kilohm per step box, connect each resistor one at a time to the unknown terminals of the bridge and measure their deviation from the standard.

28) Calculate the average deviation from the above for the first ten resistors.

29) Subtract this average value from the measured value of step 20, Section 4.3.1.

30) Add this difference to each of the individual deviations measured above.

This will be the deviation from nominal of the individual resistors, and corresponds to the first column of the calibration card attached to the end of the SR 1010.

Compare these calibrated values with those on the chart at the end of the boxes. Before replacing this chart with one using the values just determined be sure that the standards and procedures used in the new calibration were sufficiently accurate. It is also recommended that the charts not be replaced unless two or more complete calibration sequences give the same answer, preferably when performed by different operators, and even using different bridges or ratio sets if available.

4.3.3 FILLING OUT THE CALIBRATION CARD

If it has been determined that the values given on the calibration card are no longer correct the following procedure is recommended for filling out a new card.

1)	List the deviation from nominal of the individual resistors as measured in Section 4.3.2.	See Figure 4.3.3 Column A.
2)	Calculate the group average from these deviations corresponding to the group average measured in Section 4.3.1.	This group will consist of the first nine resistors for the 1 ohm, 100 ohm and 10 kilohm per step boxes and the first ten resistors for the 10 ohm, 1 kilohm and 100 kilohm per step boxes.
3)	Subtract the calculated average from the measured average to obtain the correction for the measured individual deviations.	
4)	Add the above correction to each of the measured individual deviations.	See Figure 4.3.3 Column B.
5)	Sum up each of the individual deviations from the first down to each of the subsequent deviations. For example, the cumulative sum corresponding to R4 will be the sum of the deviations of R1, R2, R3, and R4.	See Figure 4.3.3 Column C.
6)	Divide each of the cumulative sums by the number of deviations involved in the sum. For example, the cumulative sum corresponding to R4 will be divided by four.	See Figure 4.3.3 Column D.
7)	Round off the corrected individual deviations to the nearest ppm and fill in the first column of the calibration chart (labeled Individual (ppm)) with these values.	See Figure 4.3.3 sample calibration chart.

8) Round off the cumulative averages to the nearest ppm and fill in the second column of the calibration chart (labeled Cumulative (ppm)) with these values.

See Figure 4.3.3 sample calibration chart.

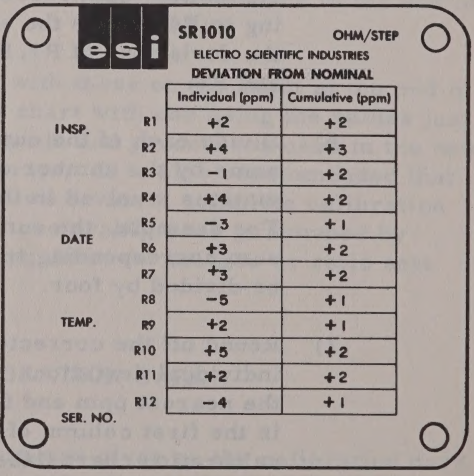
	A Measured Individual Deviations (From Section 4.3.2)	B Corrected Individual Deviations	C Cumulative Sum	D Cumulative Average
R1	+3.6	+2.1	+2.1	+2.1
R2	+5.7	+4.2	+6.3	+3.2
R3	+0.3	-1.2	+5.1	+1.7
R4	+5.3	+3.8	+8.9	+2.2
R5	-1.6	-3.1	+5.8	+1.2
R6	+4.9	+3.4	+9.2	+1.5
R7	+4.5	+3.0	+12.2	+1.7
R8	-3.2	-4.7	+7.5	+0.9
R9	+4.0	+2.5	+10.0	+1.1
R10	+6.6	+5.1	+15.1	+1.5
R11	+3.2	+1.7	+16.8	+1.5
R12	-2.7	-4.2	+12.6	+1.0

9 | 23.5 Sum
2.6 Average

Measured group average for nine resistors (From Section 4.3.1) = +1.1

Minus group average calculated from measured individual deviations = -2.6

Correction to be added to measured individual deviations = -1.5



SR1010 OHM/STEP
ELECTRO SCIENTIFIC INDUSTRIES
DEVIATION FROM NOMINAL

INSP.
DATE
TEMP.
SER. NO.

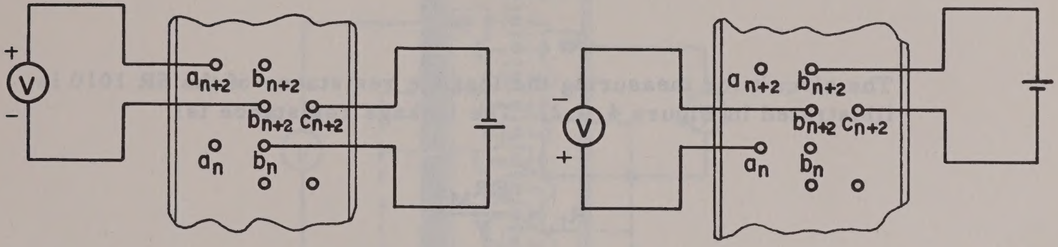
	Individual (ppm)	Cumulative (ppm)
R1	+2	+2
R2	+4	+3
R3	-1	+2
R4	+4	+2
R5	-3	+1
R6	+3	+2
R7	+3	+2
R8	-5	+1
R9	+2	+1
R10	+5	+2
R11	+2	+2
R12	-4	+1

FIG. 4.3.3

4.4 SPECIAL TESTS

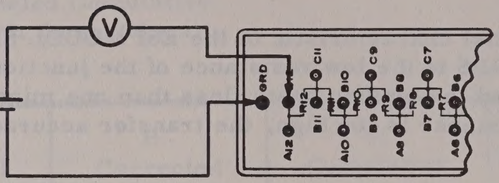
4.4.1 JUNCTION TRANSRESISTANCE

An essential characteristic of the ESI MODEL SR 1010 TRANSFER STANDARDS is the low resistance of the junction between the resistors and the binding posts (less than one microhm). If the junction transresistance is too high, the transfer accuracy of the units will be impaired.



The method of checking the junction transresistance is illustrated in Figure 4.4.1. By using a current source of one amp and a microvoltmeter capable of seeing one tenth of a microvolt the junction resistance can be measured to a tenth of a microhm. The transresistance measured by both the circuits shown and there difference should be less than 1/2 microhm. This test need be made on the one ohm per step and ten ohm per step boxes only, since the resistance of the junction material is too small to cause as much as one ppm error in a one hundred ohm per step box.

4.4.2 INSULATION RESISTANCE



The circuit for measuring the leakage resistance of the SR 1010 is illustrated in Figure 4.4.2. The leakage resistance is:

$$R_L = \frac{ER_M}{V}$$

where:

R_L is the leakage resistance from all terminals in parallel to ground in ohms.
E is the supply voltage in volts.
R_M is the input resistance of the meter.
V is the reading of the voltmeter.

R_L should be greater than 10^{12} ohms.

4.4.3 FOUR-TERMINAL PARALLELING ACCURACY OF THE SYSTEM

The uncertainty due to connection resistances of four terminal resistors in parallel is less than:

$$\pm 2\left(\frac{r}{R}\right)(d_{CR} - d_R)$$

where:

r is the greatest bus bar resistance.

R is the nominal value of the resistors being paralleled.

$(d_{CR} - d_R)$ is the greatest bridge unbalance in terms of the compensation resistors and the resistors being connected.

The values of $\frac{r}{R}$ and $(d_{CR} - d_R)$ can be measured to find the expected accuracy of a particular connection.

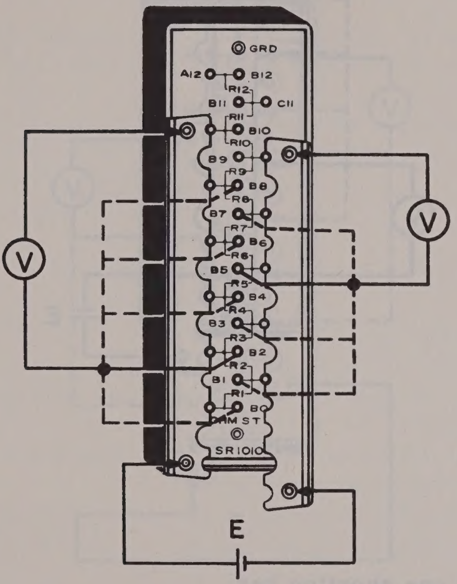


FIG. 4.4.3a

The value of $\frac{r}{R}$ can be found by measuring the voltage drops from a point on the bus bars to the junction of adjacent resistors, shown in Figure 4.4.3a.

1) Connect the shorting bar.
2) Measure voltage from a point on the bars to the unused terminals, this is the voltage to the junction of adjacent resistors.
3) Find the maximum difference of values V for each bar.
4) Use the greatest V difference to calculate $\left(\frac{r}{R}\right)_{max}$

$$\frac{V_{max} - V_{min}}{E} = \left(\frac{r}{R}\right)_{max}$$

The bridge unbalance can be measured as shown in Figure 4.4.3b. The measured values can be multiplied together and doubled to give an upper bound of the connection error. This usually includes a very substantial safety factor.

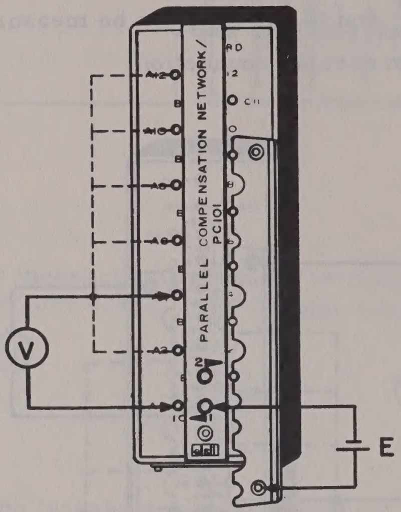


FIG. 4.4.3b

1) Connect one shorting bar.
2) Connect the compensating network.
3) Supply a voltage E from the shorting bar to the other side of the network.
4) Measure the voltage V from one unused shorting bar terminal to each of the others.
5) Change the shorting bar to the other side and repeat.
6) Find the maximum voltage difference ($V_{max} - V_{min}$) between terminals.
7) Calculate $(d_{CR} - d_R)_{max}$

$$\left(\frac{V_{max} - V_{min}}{E}\right)\left(2 + \frac{2R_0}{R} + \frac{R}{R_0}\right) = (d_{CR} - d_R)_{max}$$

4.4.4 FOUR-TERMINAL SERIES-PARALLELING ACCURACY OF THE SYSTEM

The determination of the four-terminal series-parallel accuracy is the same as that of the four-terminal parallel accuracy described in Section 4.4.3. See Figure 4.4.4a for measuring $\frac{r}{R}$ and 4.4.4b for measuring $(d_{CR} - d_R)$.

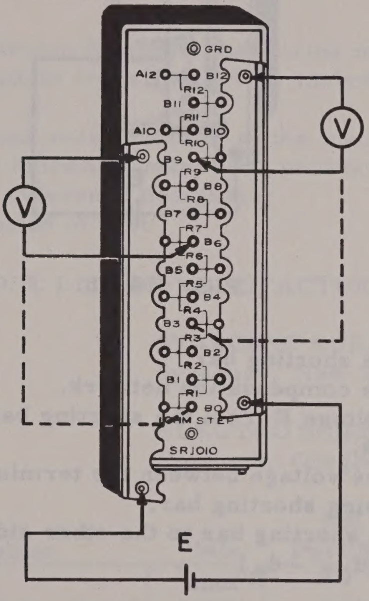


FIG. 4.4.4a

1) Connect the shorting bars.
2) Measure the voltage from a point on the bars to the terminals that would normally be connected to the compensation network.
3) Find the maximum difference of values V for each bar.
4) Use the greatest V difference to calculate $\left(\frac{r}{R}\right)_{max}$

$$\frac{V_{max} - V_{min}}{E} = \left(\frac{r}{R}\right)_{max}$$

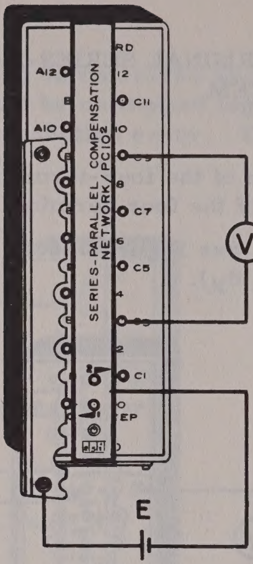


FIG. 4.4.4b

1) Connect the shorting bar.
2) Connect the compensation network.
3) Supply a voltage E from the shorting bar to the other side of the network.
4) Measure the voltage between the terminal normally connected to the missing shorting bar.
5) Change the shorting bar to the other side and repeat.
6) Calculate $(d_{CR} - d_R)_{max}$.

$$(d_{CR} - d_R) = \left(\frac{V_{max} - V_{min}}{E}\right)\left(2 + \frac{2CR}{3R} + \frac{3R}{CR}\right)$$

where:

R is the nominal value of the resistors of the SR 1010.
CR is the nominal value of the resistors in the compensation network.

SECTION V

PARTS LIST

Manufacturer of the part is given in a code number according to the Federal Supply Code for Manufacturers; see list of manufacturers below. Parts recommended as spares to sustain operation in isolated locations are indicated in the recommended spare parts column.

Parts manufactured by Electro Scientific Industries must be ordered from the factory. When ordering parts from the factory include the following information:

Model and serial number of the instrument
Electro Scientific Industries part number
Circuit reference designator
Description of part

CODE LIST OF MANUFACTURERS

11702	SYRACUSE RUBBER PRODUCTS COMPANY Syracuse, New York
11837	ELECTRO SCIENTIFIC INDUSTRIES Portland, Oregon

Description	Mfr	ESI Part No.	Qty Used	Recm SP
Cap, Binding Post, Metal	11837	1296	2	2
Cap, Binding Post, Ins.	11837	1294	26	12
Bumper, Rubber Mfr PN M-266	11702	8220	4	2
Holder, Card	11837	8535	1	1
Card, Calibration	11837	8536	1	5

DIRECTIONS

D.B. 2641-S
T.O. 33A1-12-457-1

4210

THOMAS TYPE RESISTANCE STANDARD

LEEDS & NORTHRUP

4210

THOMAS TYPE RESISTANCE STANDARD

1. GENERAL INFORMATION

The Thomas Type Resistance Standard was developed by Dr. J. L. Thomas, at the National Bureau of Standards,* as a four-terminal primary standard of d-c resistance for laboratory use where extremely high precision is required. In the L&N® 4210 adaptation, the resistance element consists of selected 12G bare manganin wire which is vacuum-annealed at 550 C, bifilar wound and mounted without stress on an insulated brass cylinder. It is hermetically sealed in the cylindrical space between its mounting cylinder and an outer brass shell. The leads are brought out to the terminals through glass-to-metal seals.

The current terminals are the arms extending beyond the edge of resistance shell. Connections can be made to the thumbscrews or the amalgamated lugs. The potential terminals are the binding posts opposite the nameplate. The resistance between the potential leads is adjusted to one absolute ohm.

2. SPECIFICATIONS

Resistance — 1 ohm absolute.

Limit of Error — The resistor is adjusted within 20 parts per million (±0.002%) of nominal value at 25 C. Each resistor is supplied with a National Bureau of Standards certificate giving the measure value (in terms of the absolute ohm as maintained at the Bureau) to 1 part per million (0.0001%) at 25 C. The stability of the resistor is such that in normal use the change in resistance per year is less than 5 parts per million (0.0005%) during the first year, and generally is less than 2 ppm per year thereafter.

The value of resistance stated on the N.B.S. certificate is the value when used as a four-terminal resistor at 25 C.

The resistance value at any temperature other than 25 C can be calculated by using the values of Alpha (a) and Beta (B) in the formula on the back of the N.B.S. certificate. The values of Alpha and Beta are supplied by L&N on an attachment to the N.B. S. certificate.

Current Rating — 0.1 ampere when immersed in stirred oil.

Terminals — Four, current/potential type.

Size — Overall width . . . . 7"

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*N.B.S. Research Paper 201, May 1930.

NBS 318
(Rev. 5-2-60)

UNITED STATES DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON 25, D. C.

National Bureau of Standards
Certificate

STANDARD RESISTOR

Submitted by

Leeds and Northrup Company
Philadelphia, Pennsylvania

Maker	Maker's serial number
Leeds and Northrup Company	1616908

Resistance in Ohms
1.000001

Temperature in ° C	Accuracy in %
25.0	0.0005

For the Director

Chester Peterson

Chester Peterson, Chief
Resistance and Reactance Section
Electricity Division

Date: April 30, 1963
Test No. 1.1/175693
Reference: A 44596

(over)

w 5-8

aah 3

Information Concerning Resistors

1. *Accuracy.* At the time of test, the value of resistance given in this certificate was probably correct to the last figure given. The accuracy shown is based upon this Bureau's record of the stability of the resistor, or, for resistors submitted for the first time, upon experience with resistors of the same type. Ordinarily, resistors submitted for calibration for the first time will be certified to 0.005 percent and their values given to 0.001 percent. On subsequent tests high-quality resistors will be certified to 0.002 percent. It is expected that the resistance value will be reliable to the accuracy given for at least 1 year from the date of test.

2. *Stability.* An investigation of data on both sealed and unsealed standard resistors tested at this Bureau showed that the average annual change did not exceed 0.001 percent for nearly 90 percent of the standards. Rapid changes of several times that amount often occur immediately after the breaking of the seal of a container. Many unsealed resistors, especially those of 100 ohms and above, undergo seasonal changes which may amount to several hundredths percent even when the average yearly change is small.

3. *Potential terminals.* The resistance given for a standard resistor having a nominal value over 1 ohm is the total resistance between the amalgamated surfaces of the terminals. For resistors with nominal values of 1 ohm or less the value given is the resistance between branch points, i. e., between potential terminals. When there is more than 1 pair of potential terminals the resistance given is for the pair for which the resistance is the smallest.

4. *Test current.* This resistor was tested in a well-stirred oil bath, and with a test current so small that the heat evolved did not affect the value of the resistance to the last figure given. For oil-filled standard resistors of the Rosa type the result of heating by a test current at the rate of 1 watt is as follows: Within about a minute after application of the test current the temperature of the resistance coil rises to a value about 1° C above that of the oil in which it is immersed. The oil and the standard resistor as a whole will then start to rise in temperature at the rate of about 10° C per hour. If the temperature is allowed to rise above room temperature by more than 10° C there is danger of a permanent change in resistance.

5. *Mercury connections.* When standard resistors are connected into a circuit by means of mercury, care should be taken to see that the bottoms of the mercury cups and the ends of the terminals of the standards are well amalgamated. To insure a low resistance, the amalgamated surfaces should be frequently scraped to remove the hard copper amalgam which gradually forms. To facilitate such cleaning it is desirable to use amalgamated flat copper blocks, with perhaps removable guide rings, rather than the usual type of mercury cups.

6. *Care of hard rubber.* Exposure of vulcanite or hard rubber to strong light results in a discoloration of the surface and the formation of a small amount of acid which materially reduces the insulation. The acid may be removed, and thus the insulation restored, by washing with water. However, this washing will not restore the original color.

7. *Temperature coefficients.* For most standard resistors the resistance at any temperature in the interval 20° to 30° C does not differ from the resistance at 25° C by more than 0.005 percent. Within this interval the change of resistance with temperature for a manganin resistor is accurately expressed by the equation

$$R_t = R_{25}\,[1 + \alpha\,(t-25) + \beta\,(t-25)^2]$$

where R_t is the resistance at t° C, R_{25} is the resistance at 25° C and α and β are constants. Experience shows that the coefficients α and β do not change appreciably with time and hence need to be determined only once.

For further information regarding standard resistors, see National Bureau of Standards Circular 470, Precision Resistors and Their Measurement. This publication is available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., for 30 cents.

U. S. GOVERNMENT PRINTING OFFICE 16—74708-1

Pioneers in Precision

LEEDS & NORTHRUP COMPANY 4901 STENTON AVE · PHILADELPHIA 44, PA · 215 DA9-4900

TEMPERATURE COEFFICIENT DATA

FOR

CATALOG NO. 4210 STANDARD RESISTOR

SERIAL NO. 1616908

-o0o-

The temperature coefficients for the above designated standard resistor are as follows:

Alpha (α) = +0.000002

Beta (β) = -0.0000005

LEEDS & NORTHRUP COMPANY

For the Director of Manufacturing

K. A. Walch

K. A. Walch
Head, Standardizing Laboratory

May 13, 1963

Outside diameter . . . . 3-3/4"

Overall height . . . . 6-1/2"

Weight — 3 pounds.

3. INITIAL PREPARATION AND MAINTENANCE

The only preparation and maintenance necessary is the initial and periodic amalgamation of the current terminal lugs. The lugs should have a clean, bright coating of chemically pure mercury.

To accomplish amalgamation, thoroughly clean the contact surface of the lugs with fine grain sandpaper and carefully wipe each contact surface with a clean cloth. Fill a one-half fluid ounce bottle about one-half full with chemically pure mercury and add a small piece (about 1/8 inch cube) of metallic sodium. Shake the bottle gently until the mercury flashes.

WARNING: Keep face away
from the open end of bottle
while shaking.

Turn the resistor upside down. Moisten the contact surfaces with a drop of water and with an eyedropper place a drop of sodium prepared mercury on each contact surface. When contact surfaces are thoroughly amalgamated, wash thoroughly with water, otherwise the amalgam will become green and form high resistance contact surfaces. To complete the process, empty the contents of the eyedropper into the bottle containing the sodium prepared mercury. Wash out the dropper with water. Refill with chemically pure mercury, and place a drop on each contact surface. The mercury will now adhere to the ends of the lugs to form a low resistance contact surface with high conductivity characteristics.

The procedure outlined above should be repeated as often as the ends of the lugs require it.

4. OPERATION

These units must always be used as four-terminal resistors. The current connections can be made to either the amalgamated ends of the lugs (used with mercury-cups) or the thumbscrews in these current terminals. The potential connections are made to the two potential binding posts. Additional information can be obtained from N.B.S. Circular 470 entitled "Precision Resistors and Their Measurement".*

5. ACCESSORY COMPONENT

1 — Adjustable Mercury Cup Stand, L&N Part No. 127287.

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*Available from the U.S. Government Printing Office, Washington, 25, D.C.

6. REPAIR INSTRUCTIONS

Except for a few replaceable parts, the L&N 4210 is not repairable. The parts are listed in Section 8.

7. ACCESSORY COMPONENT

1 — Adjustable Mercury Cup Stand, L&N Part No. 127287.

8. PARTS AND PRICE LIST

DETAIL NO.	QUANTITY	PART NO.	DESCRIPTION	UNIT PRICE*
1	2	Dwg. No. H-789-3	Clamp Screws (Det. No. 2)	$3.50**
2	2	Dwg. No. H-789-3	Heads (Det. No. 5)	2.90**
3	1	71-1-0-1	Catch	.80
4	4	004729	3/16" 4-40 R.H.B. CR.P. Screw	.10
5	1	046055	Handle	.50
6	2	046041	Handle Mounting Posts	.30
	1	038028	Plastic Bag	.10

*Prices subject to change without notice.
**Minimum order — ten (10).

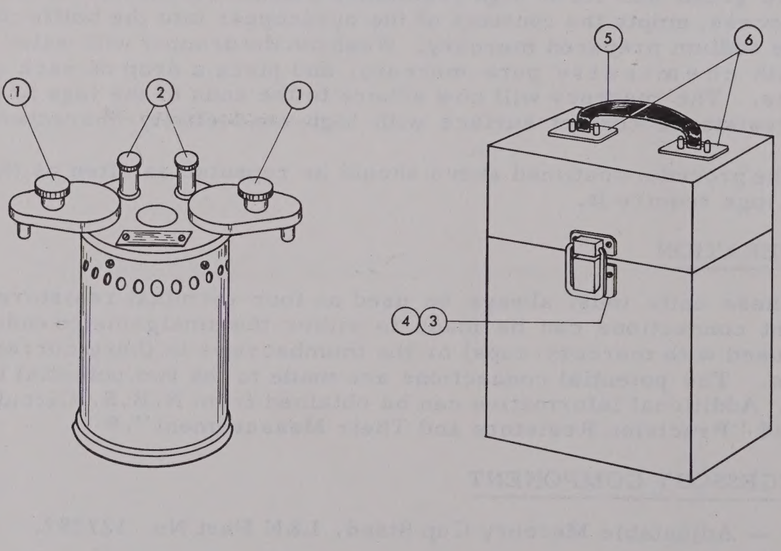

Fig. 1

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Guildline Instruments Limited,
Smiths Falls, Ontario, Canada.

STANDARD CELL ENCLOSURE

TYPE 9152R

Serial No. ..74031 Operating Temperature ..35...°C

Patent Applied For.

OPERATING INSTRUCTIONS

The 9152R Standard Cell Enclosure is intended to accomodate 3 Type 4305 saturated standard cells and to maintain their temperature constant to within ±0.01C° of nominal. The unit is supplied from a 110 volt 60 cycle line but is also provided with standby facilities os that in the event of line failure automatic change-over to 12 volt battery supply takes place.

1) Installation

Connect the 2 pin plug to a power outlet, (110V/60c or 220V/50c as marked on the instrument). The amber and green "ON" and "OFF" lamps will indicate that the outer cylinder of the heated compartment has reached its operating temperature, but due to thermal lagging several hours will be required before the inner cylinder which contains the standard cells reaches the operating temperature. Simultaneous illumination of both "ON" and "OFF" lamps at reduced brilliance is not unusual and is not abnormal operation.

2) Principle of Operation

Changes in temperature in the wall of the outer of the two concentric cylinders are sensed by a small thermistor which, in conjunction with the high stability resistance R$_1$ forms a voltage divider across the 1:2 ratio auto-transformer T. When the output from the voltage divider into the base of

transistor T_1 exceeds 0.5 of the autotransformer output, as would occur with increase of thermistor resistance due to decreased temperature, the emitter to base gain exceeds unity and the circuit oscillates.

The oscillatory signal is amplified and rectified and used to close a transistor switch controlling the heater current. The resulting increase in temperature decreases the thermistor resistance, the ratio between the output voltage of the divider and the input voltage to the auto-transformer falls below unity, oscillation stops, the signal is removed from the transistor switch and the heater current is switched off.

The detector is sensitive to changes less than 0.001C° with the result that when a stable temperature is achieved the switching action is extremely rapid. The "ON" and "OFF" lamps may switch clearly from dark to full brilliance, or may flicker at the instant of change over or under some conditions may achieve a balance at on intermediate point with both "ON" and "OFF" lamps illuminated at reduced brilliance.

3) Overtemperature Protection

An auxiliary thermostat is set to operate a few degrees above the normal control temperature. This provides protection against damage to the standard cells in the event of a failure of the temperature control system. Excessive temperature rise is prevented by the closing of the thermostat which effectively places the series heater fuse directly across the supply, and at the same time causes the red lamp on the front of the instrument to light.

The fuse is located on the terminal board inside the control unit of the instrument. In the event of a failure the cause should be corrected before the

fuse is replaced.

4) Line Supply Failure

During line supply operation a transistor is biased off by the charge on a 50uF capacitor. This capacitor is charged to the peak voltage of the rectified 12 volt supply from the transformer. When the line supply is disconnected the bias disappears and the transistor is allowed to conduct. The standby battery then supplies the transistor switch and heater. The maximum current taken from the battery with the heater fully on is approximately 0.5 ampere. The average current depends on the operating and ambient temperatures, and for a 30°C unit operating in an ambient temperature of 22°C is of the order of 0.25 ampere.

5) Heating during Transportation

The enclosure can be maintained at operating temperature during transportation by connection of the "STANDBY 12V" terminals to a 12V battery or to a car cigaret lighter socket. Connection of the 12V supply in the wrong polarity cannot damage the unit but it will not operate with polarity reversed. After connection of the 12 volt supply check that either the "ON"or "OFF"lamp is glowing when the line supply is disconnected.

6) Measurement of internal temperature

The circuit of the internal thermistor bridge is shown in the attached drawing. Two of the bridge arms are fixed manganin resistors. The third arm contains a thermistor and the fourth arm may be varied over a resistance range equivalent to a thermistor temperature change of ±0.06C° by means of the calibrated dial on the front panel and by an internal trimmer which is pre-set at the factory and which should not require further adjustment. The thermistor bridge is

located in the inner enclosure immediately adjacent to the standard cells. This bridge is not intended for the measurement of absolute temperature. It is intended only for the measurement of temperature deviation from nominal. When the cells are certified, the operating temperature as indicated by the dial is recorded, and thereafter it is necessary to know only that the cell temperature is unchanged. This is indicated by the thermistor bridge balance point. To check the cell temperature connect a galvanometer to the terminals marked "GALV" and a 1.5 volt dry cell to the "BATT" terminals. Adjust the front panel dial for null deflection on the galvanometer and read the temperature deviation from nominal on the dial engraving. The galvanometer should have a current sensitivity of approximately 0.000 5uV/mm (2000 mm/uA).

7) Effect of ambient temperature

The temperature of the cells as indicated by the thermistor bridge can be expected to follow changes in room temperature with a ratio of change of 5 Centigrade degrees would change the internal temperature by about 0.01°C.

8) Certification

If the voltage of the standard cells is to be determined by direct comparison with a national standard of voltage as maintained by the Canadian National Research Council or the U.S. National Bureau of Standards the comparison should be made with the cells inside the enclosure at operating temperature. THE CELLS AND ENCLOSURE SHOULD BE TRANSPORTED WITHOUT REMOVAL OF THE CELLS. After transportation or if the enclosure has been allowed to cool, the cells should be allowed to stabilize at operating temperature for at least 10 days before measurement or before use. The enclosure can be expected to achieve operating temperature after cooling, within approximately 48 hours.

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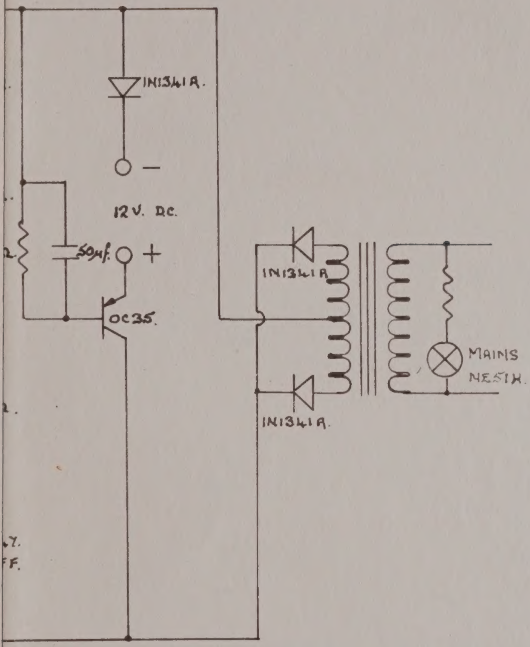
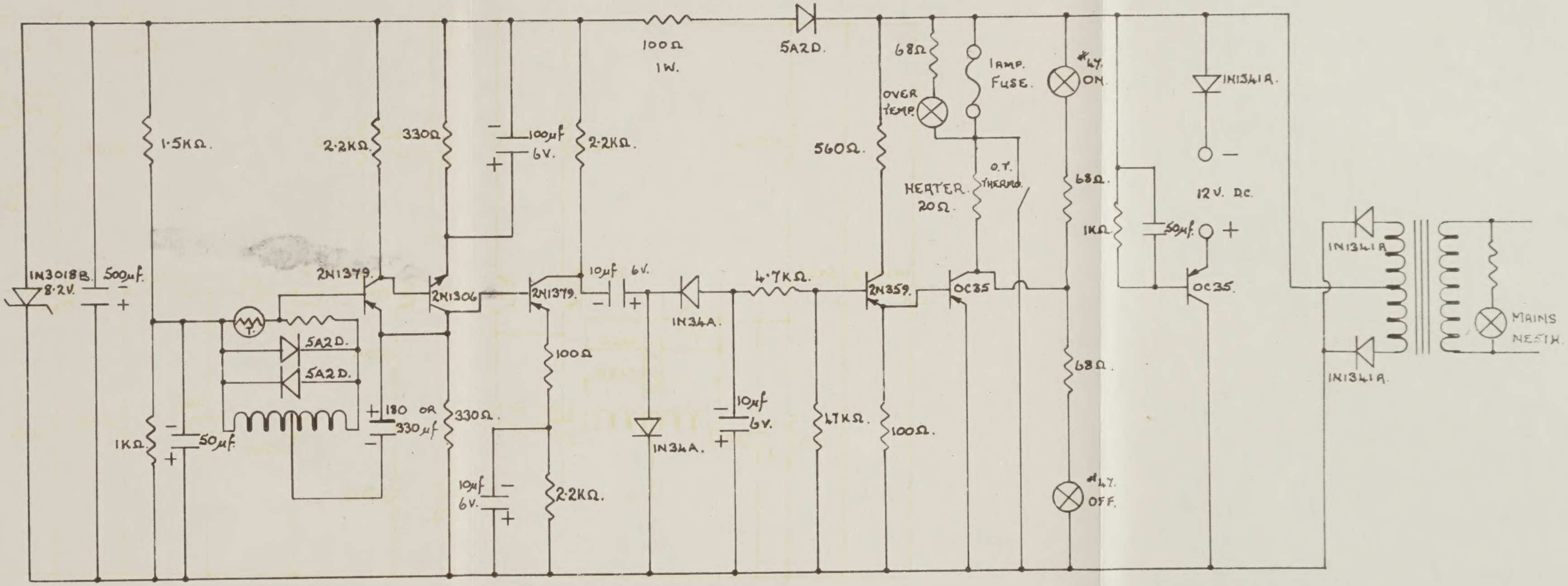


NTS LTD

STANDARD CELL ENCLOSURE.

CONTROL CIRCUIT.



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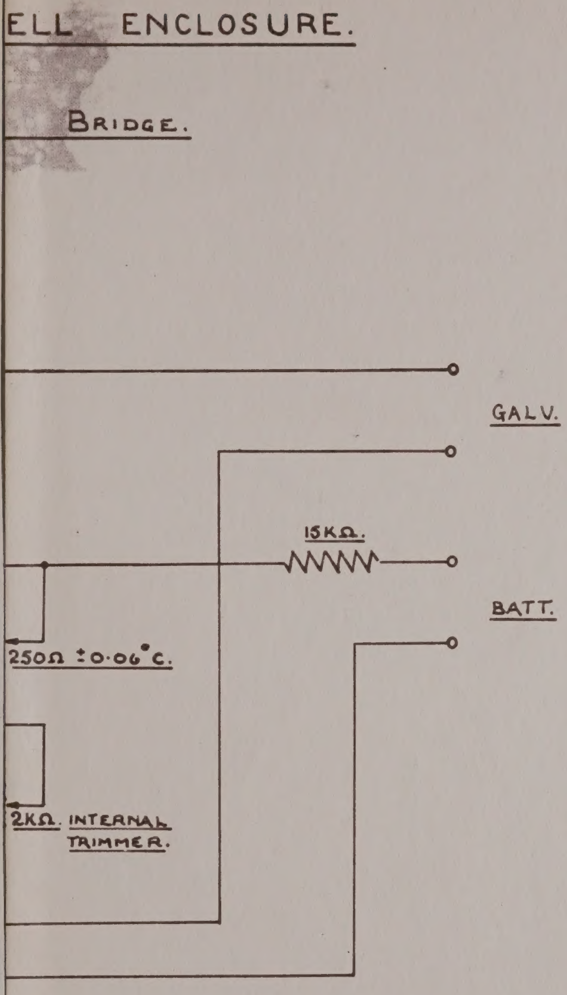

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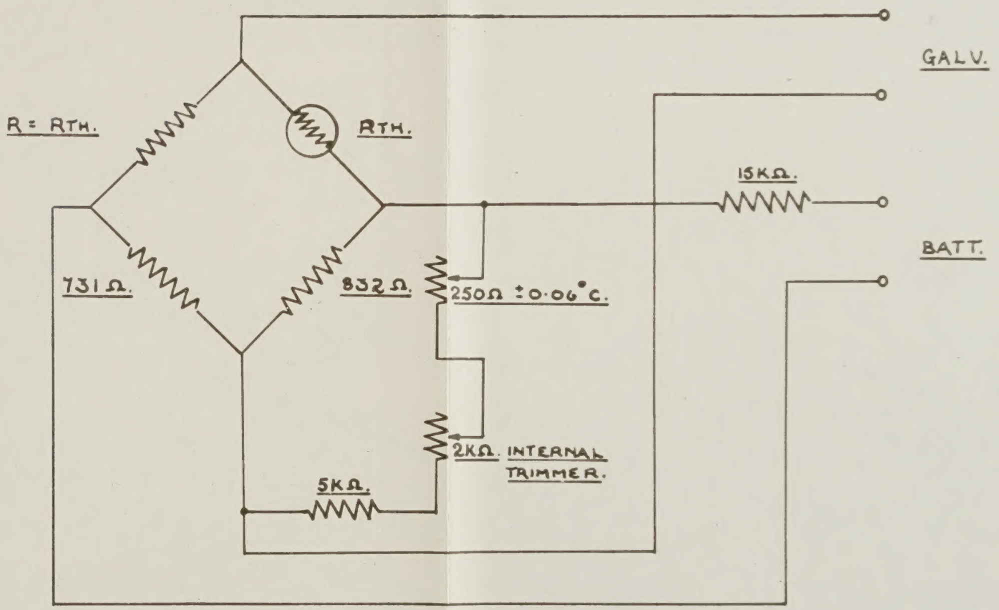
STANDARD CELL ENCLOSURE.

THERMISTOR BRIDGE.



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ISSUE — 5.

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